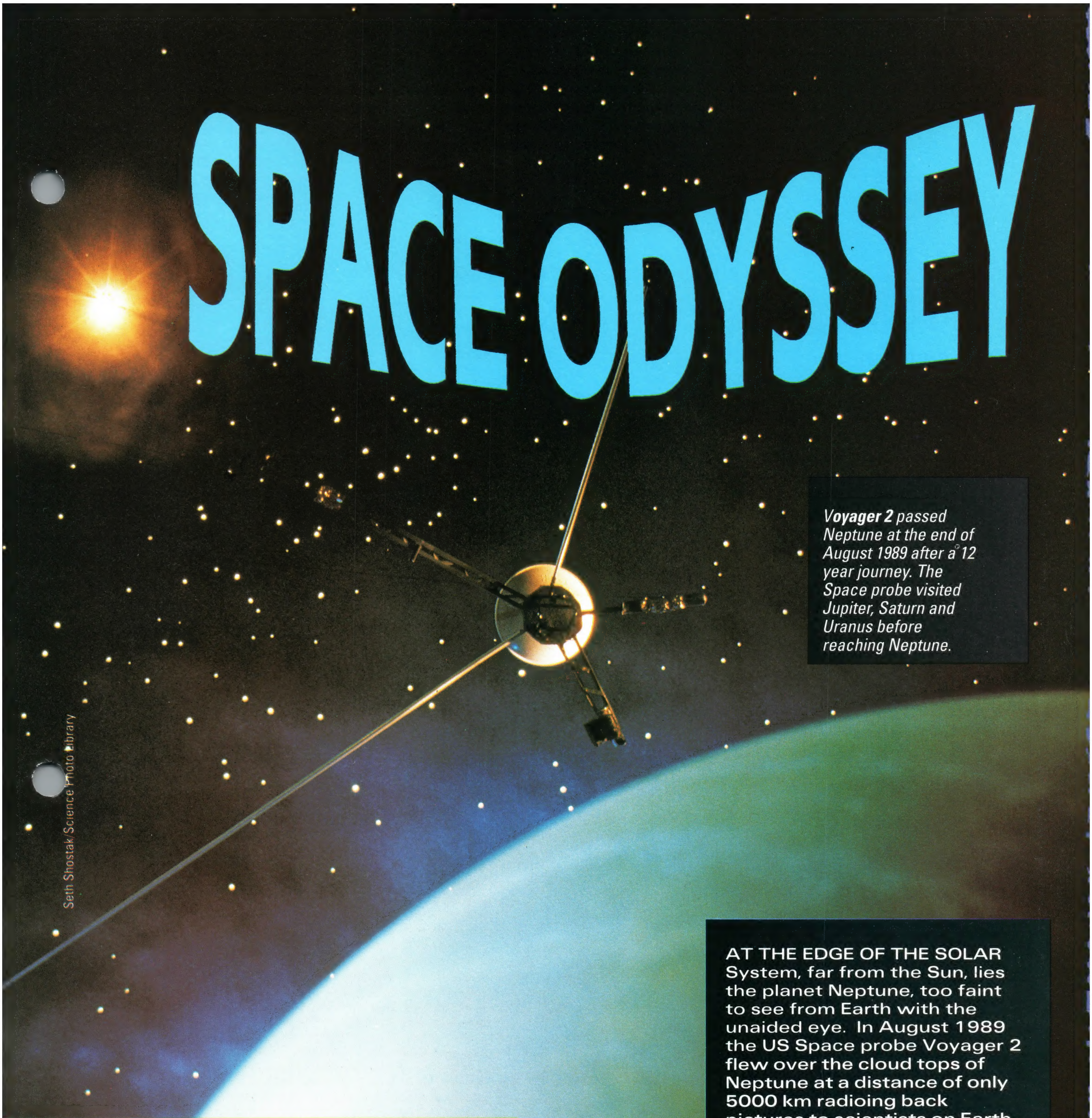
SPACE ODYSSEY



Voyager 2 passed Neptune at the end of August 1989 after a 12 year journey. The Space probe visited Jupiter, Saturn and Uranus before reaching Neptune.

AT THE EDGE OF THE SOLAR System, far from the Sun, lies the planet Neptune, too faint to see from Earth with the unaided eye. In August 1989 the US Space probe Voyager 2 flew over the cloud tops of Neptune at a distance of only 5000 km radioing back pictures to scientists on Earth.

These pictures revealed the planet to be a blue-green ball of gas surrounded by thin rings of debris and a family of eight moons, only two of which had previously been seen from Earth. Among Neptune's clouds is a great dark spot the size of Earth plus bright, high, cirrus clouds of frozen methane.

Icy volcanoes

The surface of Neptune's largest moon, Triton, is covered in pink ice with jumbled ridges and grooves. Perhaps the greatest surprise is signs of ice volcanoes on Triton, fed by underground pools of liquid nitrogen that erupt on to the surface of this frozen world.

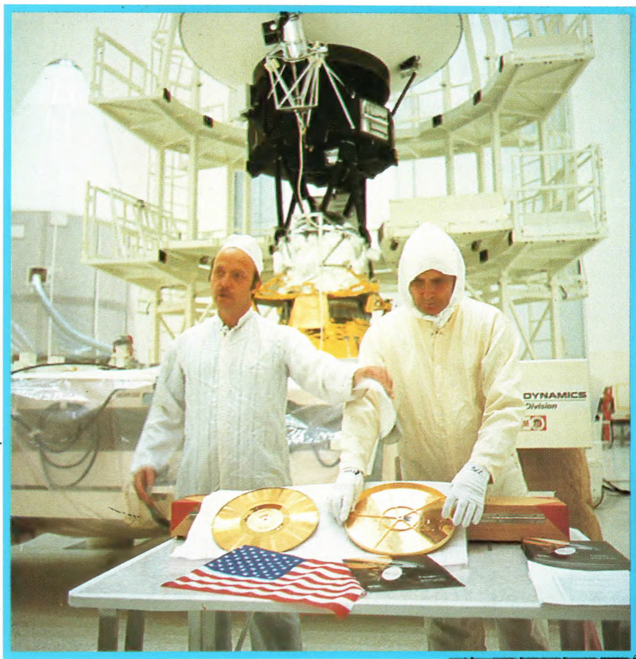
***Mission control** at NASA's Jet Propulsion Laboratory in California during Voyager 1's encounter with Saturn in October 1989.*

The Neptune encounter completed a remarkable 7-billion-km odyssey that had begun 12 years earlier with the launch of Voyager 2 and its identical sister ship Voyager 1 from Cape Canaveral in Florida. Each Voyager craft's most obvious features are a radio dish measuring 3.7 metres across, through which it sends information back to Earth, and a 13-metre-long arm on which are mounted instruments to detect weak magnetic fields. This long arm keeps the instruments away from the magnetic field of the spacecraft itself.

TV cameras

Instruments for studying the planets, including two TV cameras for taking wide-angle and telephoto pictures, are on a shorter arm. A third arm holds the spacecraft's power supply, which converts heat from the radioactive decay of plutonium into electricity. Travelling far from the Sun, the Voyagers cannot use energy from sunlight to provide electricity.

The probes' first target was giant Jupiter, largest of the nine planets in the Solar System. Jupiter is enveloped in storm-tossed clouds that are drawn out into belts as the planet rapidly rotates. Beneath the clouds are seas of liquid hydrogen. Jupiter, like the other outer planets visited by the Voyagers, has no solid surface, so we could never land there.



NASA/Science Photo Library

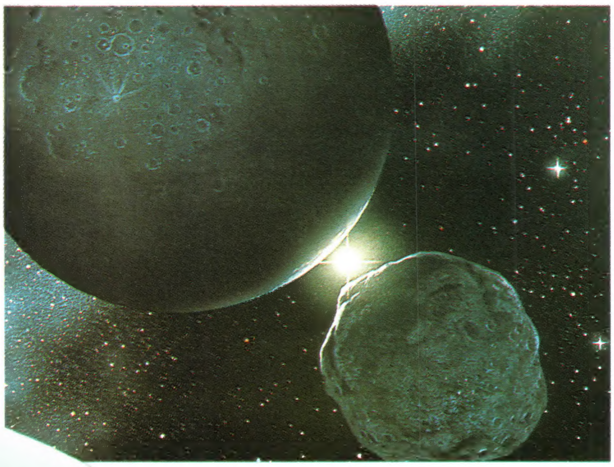
The American flag *and a special record entitled Sounds of the Earth were stored aboard Voyager 2 as evidence of life on Earth, in case Voyager meets life elsewhere. The record contains greetings in 60 languages, music, the sound of the wind, animal noises and electronically imprinted words and photographs.*

It would be dangerous to approach too close to Jupiter, since it has a strong magnetic field that traps atomic particles. As the Voyagers passed Jupiter they were bathed in radiation one thousand times the lethal dose for humans.

Jupiter has spectacular and colourful clouds, tinted yellow and red by chemicals. The Voyager cameras zoomed in on an eye-shaped storm cloud, the Great Red Spot, large enough to swallow three Earths.

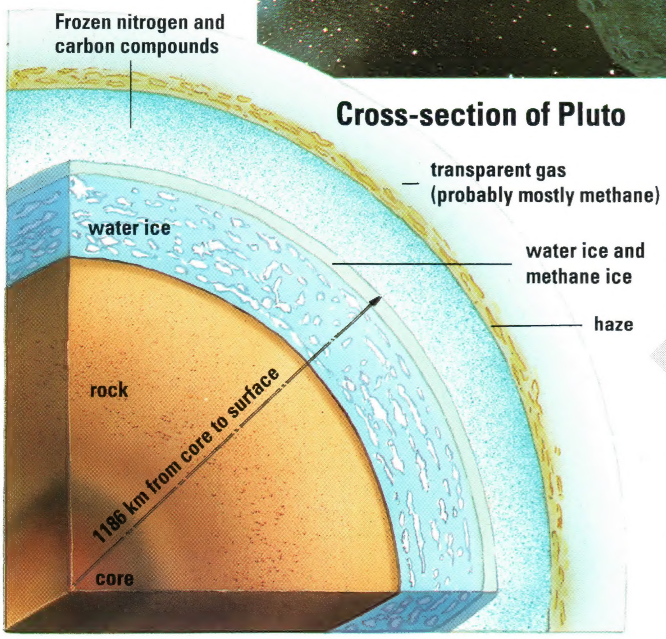
ZEFA

Television cameras *aboard both Voyager spacecraft took high-resolution photographs of the atmosphere and features of each planet encountered.*



David A Hardy/ Science Photo Library

Pluto, *the most distant planet from the Sun yet discovered, was first spotted in 1930, and Pluto's moon Charon was only discovered as recently as 1978. Charon, 19,640 km from Pluto, is half as big across as Pluto itself; some scientists have even described the two as a 'double planet'.*



John Houghton

The only planet *in our Solar System that has not been visited by a Space probe from Earth is Pluto. Astronomers observing the planet from Earth have calculated that Pluto is almost twice as dense as water. It was first thought that Pluto was made of solid methane, but methane has too low a density, so scientists now believe Pluto must be largely rock.*

Orange moon

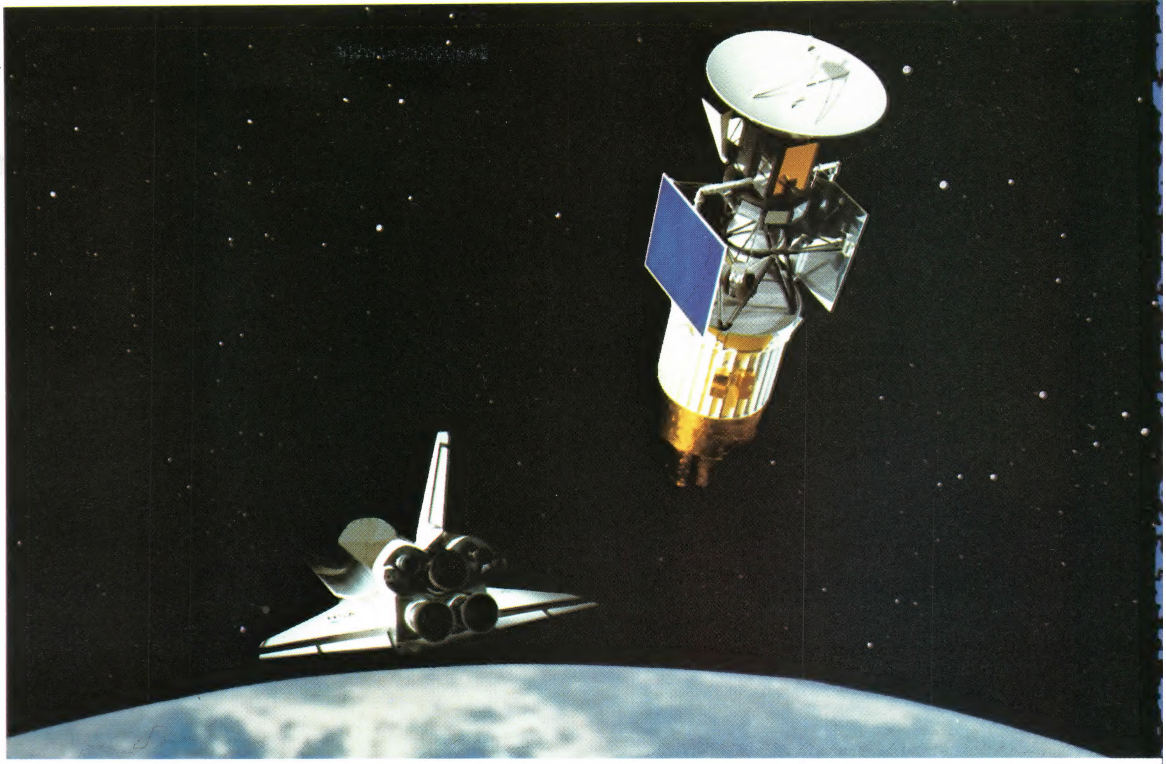
Jupiter's two largest moons, Ganymede and Callisto, are cratered by the impacts of meteorites, while another moon, Europa, has a smooth, icy surface veined by cracks. Most spectacular is the moon Io, the surface of which is covered with orange sulphur. Fountains of liquid sulphur erupt from Io's interior as if the moon were slowly turning itself inside out.

Saturn's rings

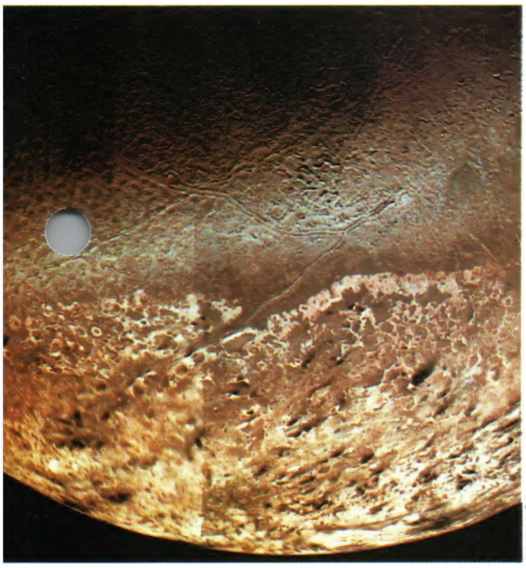
From Jupiter, the Voyagers travelled to Saturn, perhaps the most beautiful planet in the Solar System because of the bright rings that girdle its equator. These are composed of countless tiny ice-covered rocks – possibly the building blocks of a moon that never formed. In close-up, the rings of Saturn were seen to consist of thousands of threadlike

Magellan *was carried into Space in the cargo bay of Space Shuttle Atlantis in May 1989. The probe then left the Shuttle to begin its 15-month journey to Venus. Magellan mapped Venus's surface using radar and recorded features as small as 10 km across.*

JPL/NASA



Voyager 2's *cameras took more than 9,000 pictures of Neptune and its largest moon, Triton (below), in August 1989 and transmitted them 4.5 billion km to Earth. Scientists learnt far more from these images than they could using telescopes.*



JPL/NASA

Just amazing!

CAN YOU HEAR ME?

WHEN THE SIGNALS FROM VOYAGER 2 AT NEPTUNE REACHED THE EARTH, THEY WERE 20 BILLION TIMES WEAKER THAN THE BATTERY POWER THAT RUNS A DIGITAL WRISTWATCH.

Paul Raymonde

ringlets, resembling the surface of a long-playing record.

The Voyagers also discovered several new moons, as they did at every planet they visited. Saturn itself, although similar in composition to Jupiter, has less colourful clouds, because high-altitude haze masks the cloud features from view.

On to Titan

Saturn's largest moon, Titan, is wrapped in a smoggy atmosphere of nitrogen – the main constituent of the Earth's atmosphere. Titan possesses simple organic compounds that might have evolved into life had Titan, at nearly ten times Earth's distance from the Sun, not been so cold.

After passing Titan, Voyager 1's path was bent upwards and away from the plane in which the planets orbit the Sun. But Voyager 2, which did not pass so close to Titan, was put on course for the next planet, Uranus, which it reached at the beginning of 1986.

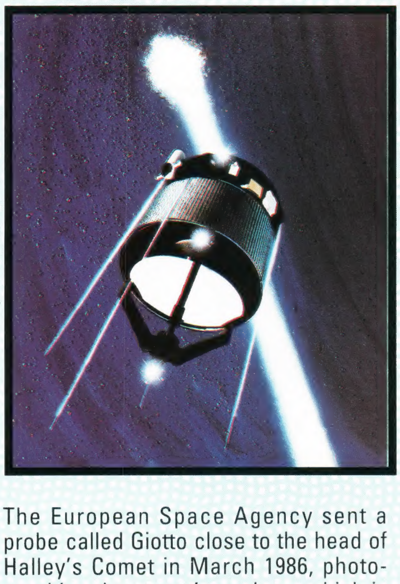
Fifteen moons

Following the excitement of Jupiter and Saturn, Uranus looks bland, being a virtually featureless, blue-green ball. Main scientific interest focused on its rings (known from Earth but never seen in detail before) and its moons, of which Voyager 2 discovered ten to add to the five already known. Most astounding of all is the moon Miranda, which has a jumbled terrain that suggests it has broken apart and then reassembled at least once since its original formation.

By the time it reached Neptune, Voyager 2 was so far from Earth that its radio signals, even travelling at the speed of light, took over 4 hours to reach us. Both Voyagers are now heading off into the Galaxy and controllers expect to be able to keep in touch with them until their signals become too faint to hear, in about the year 2020.

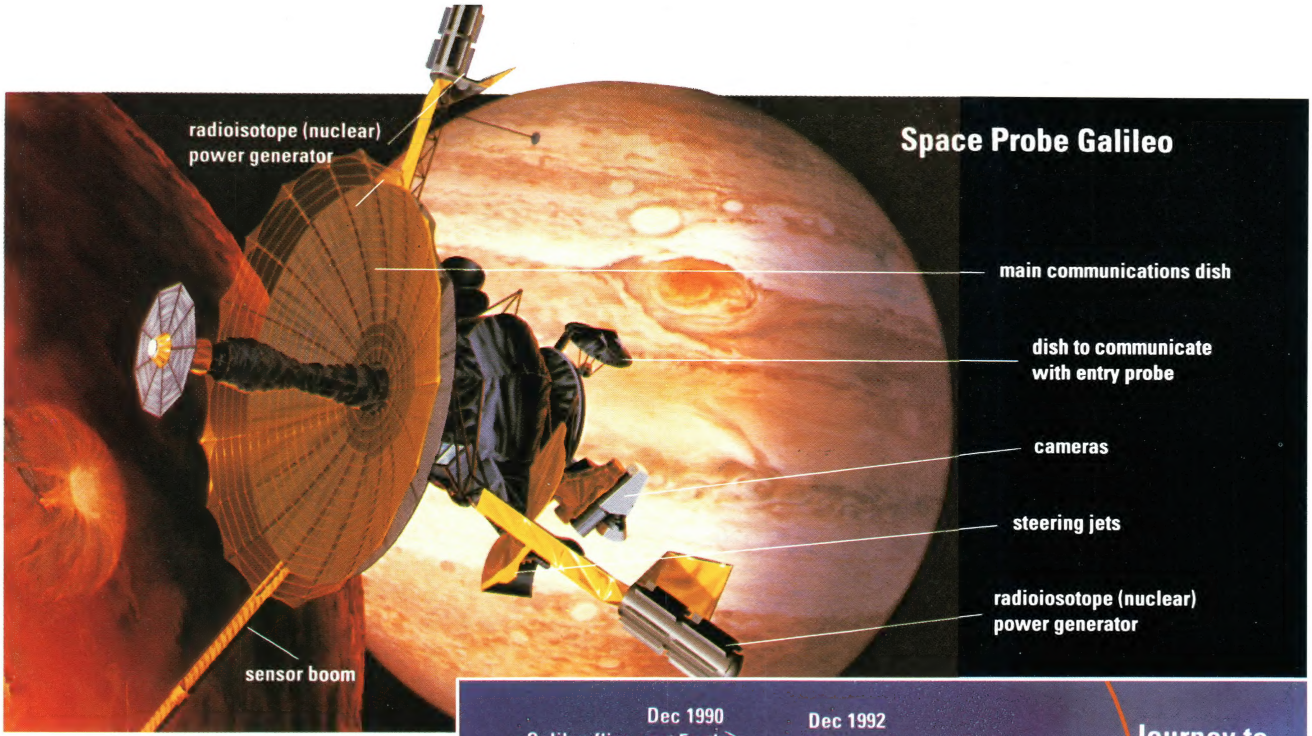
The success of Voyager 2 means that all the planets have now been visited by Space probes with the exception of tiny Pluto, which was not in the right position to be reached by either of the Voyagers. However,

PROBING A COMET

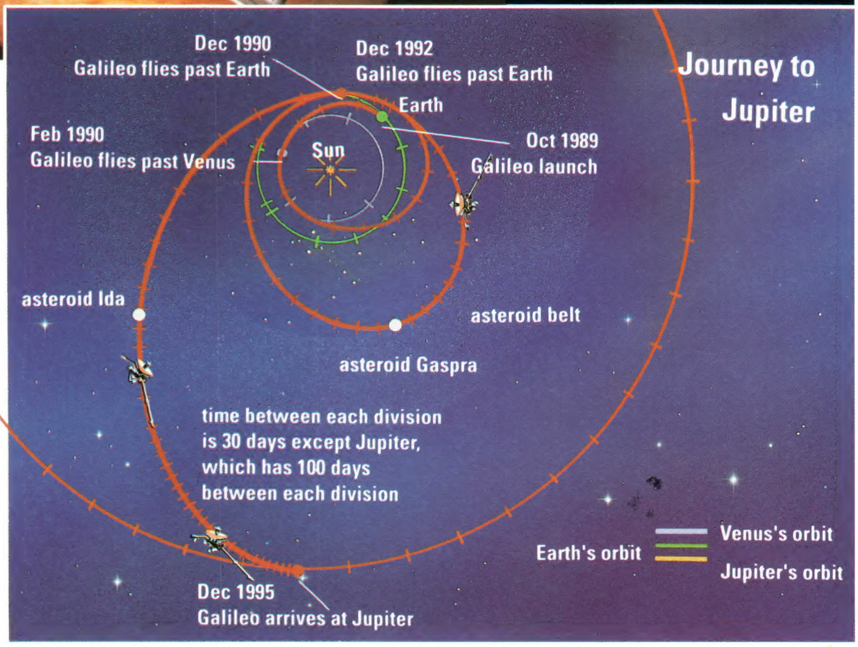


British Aerospace (Space Systems) Ltd

The European Space Agency sent a probe called Giotto close to the head of Halley's Comet in March 1986, photographing the comet's nucleus, which is made of frozen dust and gas and measures about 10 km across. The nucleus has been likened to a huge dirty snowball. Dust and gas sprayed out from the nucleus form the comet's tail. Halley's Comet orbits around the Sun, passing close to Earth every 75 to 76 years; it will next return in 2061.



JPL/NASA



NASA/Paul Desmond

Unmanned spacecraft Galileo *set off for Jupiter in October 1989. Rocket thrust and the gravitational pull of Jupiter's moon Io (shown behind the craft) will place Galileo into orbit around Jupiter – six years later. Rocket thrust also powered Galileo's break out of Earth orbit, but the probe must use the gravitational boost provided by the planets Earth and Venus to reach Jupiter.*

Pluto is thought to resemble Neptune's moon Triton.

The first Space probe to reach another planet and send back information was the American Mariner 2, which passed Venus in December 1962. Venus, a planet whose surface is permanently shrouded by dense clouds of sulphuric acid, was found to be intensely hot, with a surface temperature of about 450°C.

Since then, the Soviet Union has landed probes on Venus and in May 1989 a new Venus probe, Magellan, was launched by NASA from the Space Shuttle Atlantis. Magellan reached Venus in August 1990 and went into orbit around the planet, mapping its surface in detail by radar, which can 'see' through the clouds.

One question scientists hoped to answer was why Venus and Earth, although similar in size, have evolved so differently. They wanted to find out why Venus suffered a build up of gases that prevented heat from the Sun from radiating back into Space, trapping it in the planet's atmosphere, in the hope that this knowledge would help prevent a similar catastrophic 'greenhouse effect' from occurring on Earth.

LIFE ON MARS?

Mars was first flown by in July 1965, by American space probe Mariner 4. Two US probes called Viking landed on Mars in 1976 to look for signs of life, but found only a barren, rocky desert. The Viking probes did, however, discover that in the past the planet was both warmer and wetter than it is today – conditions in which life might have existed. Now, both the USA and Russia intend to find out more. Mars Surveyor, the US mission, consists of an orbiter to be launched in 1996 and a lander in 1998, while Russia's probes, Mars-96 and Mars-98, consist of both an orbiter and lander, also to be launched in 1996 and 1998.

Galileo to Jupiter

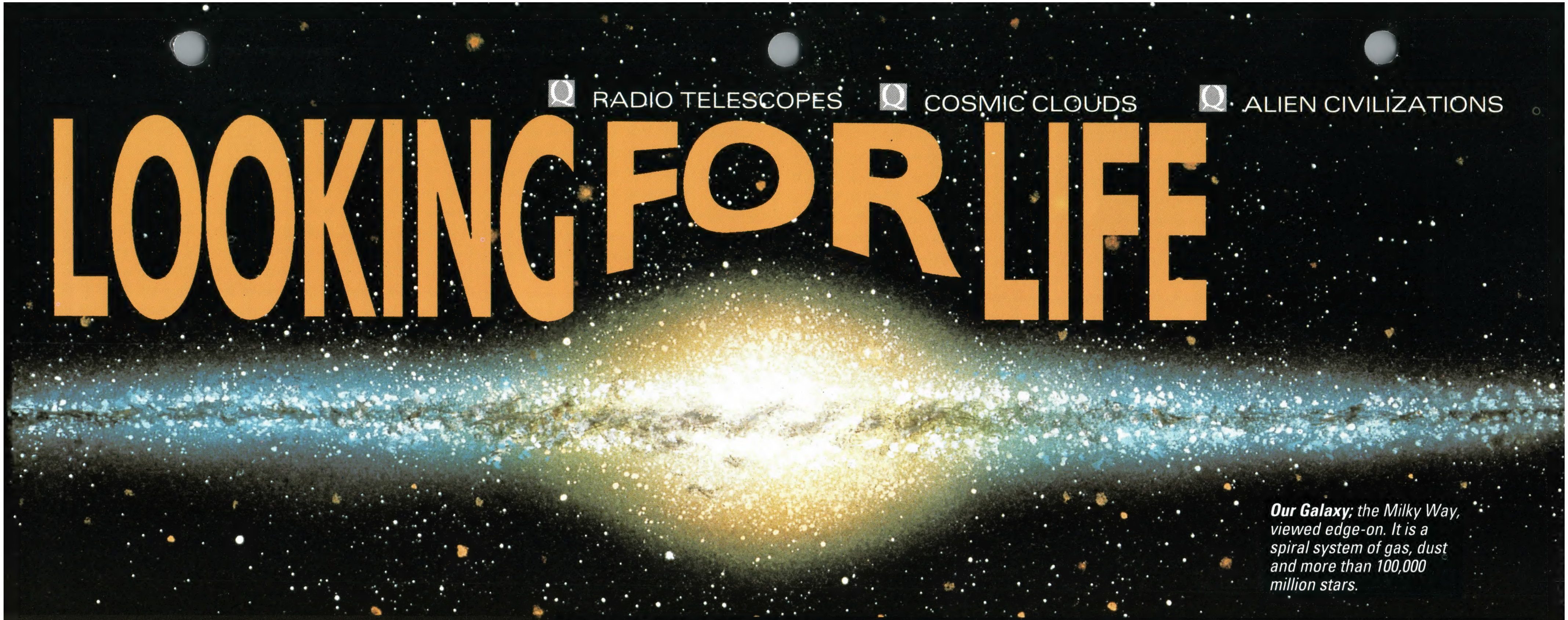
In October 1989, a probe called Galileo was launched to continue the exploration of Jupiter. It will reach Jupiter in a roundabout way, first flying past Venus in February 1990 and then looping twice past the Earth – the first time in December 1990 and then again two years later. The rocket that powered Galileo's path away from Earth could not put it directly on course for Jupiter. Each planetary flyby speeded the Space probe up until it was moving quickly enough to reach Jupiter.

This complex flight path has its advantages, for Galileo was able to study Venus, Earth and the far side of our Moon on its way. It also photographed the asteroids Gaspra and Ida, which lie between Mars and Jupiter.

Death plunge

Galileo carries a small sub-probe that will plunge into the clouds of Jupiter, sending back information on atmospheric composition, pressure, temperature and winds for over an hour before it is destroyed. The main craft will go into orbit around Jupiter, monitoring the planet's weather and taking a close-up look at its main moons, including the sulphur volcanoes on Io. A similar probe, Cassini-Huygens, is planned for Saturn early in the 21st century.

LOOKING FOR LIFE



Our Galaxy; the Milky Way, viewed edge-on. It is a spiral system of gas, dust and more than 100,000 million stars.

ON AN ALIEN PLANET LIT BY the harsh glare of a strange sun a scientist turns a large radio dish towards the sky.

Hundreds – or even thousands – of years later those faint signals are picked up by another radio telescope on a planet orbiting a different star. The first interstellar message has been received across the light years of the Galaxy. The receiving civilization knows that it is not alone.

Such a scene may already have occurred. It could occur again one day soon – and ours could be the civilization on the receiving end.

Radio telescopes are so powerful that they can transmit a message to anywhere in our Solar System. Astronomers are already pointing radio-telescopes at stars in the hope of picking up radio messages, but as yet no signals have been received. We may search many thousands more stars before we pick up a message – if there are any messages to be heard.

The chances of other civilizations like ourselves existing in Space are high. Our Galaxy alone contains at least 100,000 million stars. Even if only 10 per cent of these stars possess planets and if only a small fraction of all planets can support life, there could still be millions of places where life might exist.

Origins of life

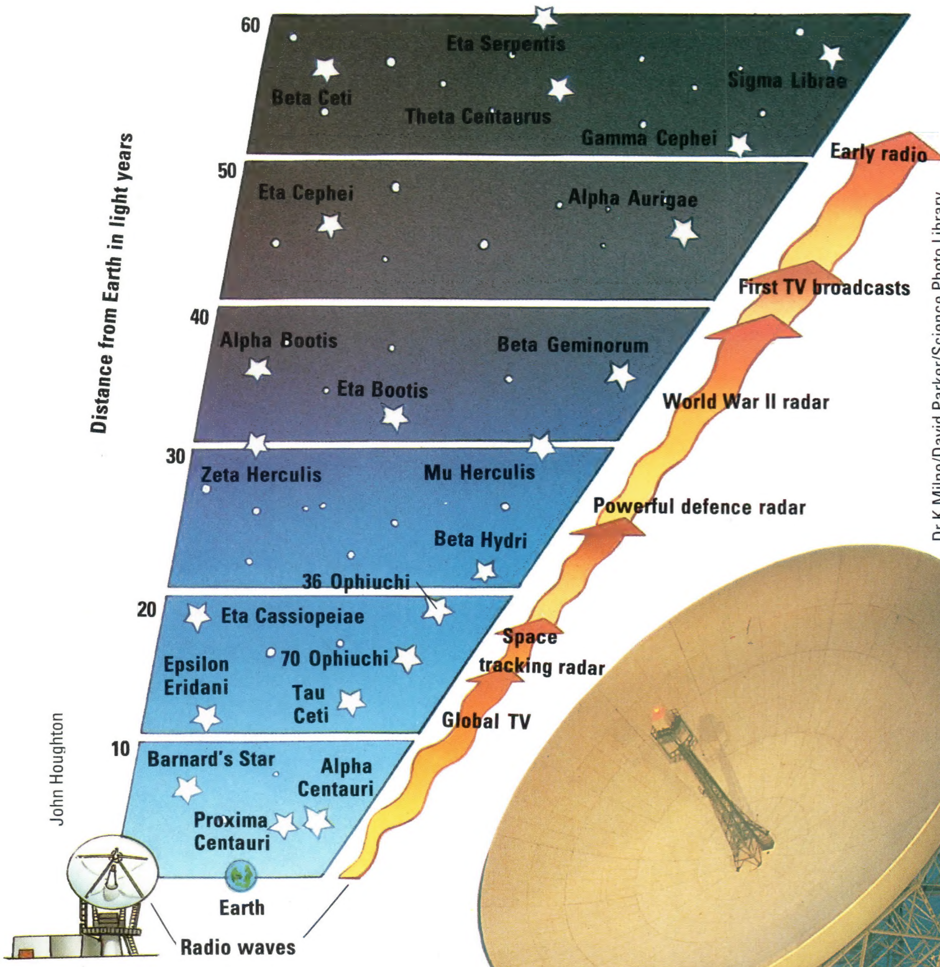
What we do not know is how life begins. Biologists are still trying to piece together the first steps to life. Living things on Earth are made up of some of the most common substances in the Universe – chemicals that contain carbon, hydrogen, nitrogen and oxygen.

On Earth, these chemicals somehow assembled themselves into primitive plants over 3,000 million years ago. In the vast span of time since then more complex forms of life have evolved and the most intelligent beings – humans – are naturally asking questions about their environment in Space.

Galactic neighbours

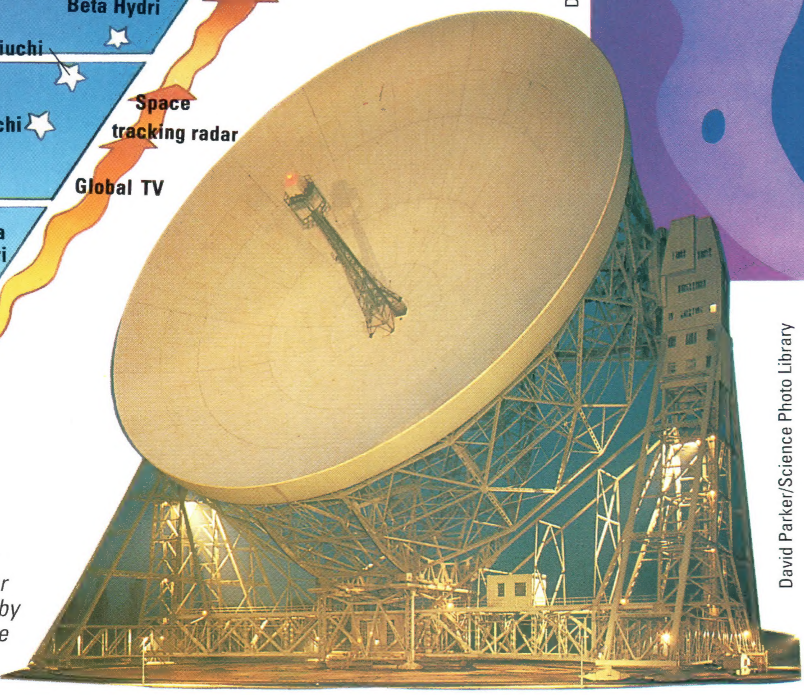
Not all these steps will necessarily be repeated on other planets where life exists. In some places life may progress no further than simple plants, while dinosaurs may still dominate other worlds. But scientists estimate that as many as a million civilizations like ours could have developed in the galaxy. How many

Making Waves In Space



John Houghton

***Radio waves** sent out in early transmissions have already travelled 50 light years into Space. Some of the stars they have reached are similar to our Sun. If these stars are orbited by planets, in the same way as the Earth orbits the Sun, then it is just possible that life has evolved on them.*



***The Lovell Telescope** in the UK captures astronomical radio waves in its 76-metre-diameter dish. The signals are amplified and filtered before being fed to the telescope's computer. Red lights on the focus box serve to warn low-flying aircraft.*

Just amazing!

POWER VISION

ACTING TOGETHER, THE EIGHT ANTENNAE OF THE AUSTRALIA TELESCOPE NETWORK ARE SO POWERFUL THAT THEY COULD BE USED TO READ THE PRINT OF A TELEPHONE DIRECTORY AT A DISTANCE OF 10KM.

Paul Raymonde

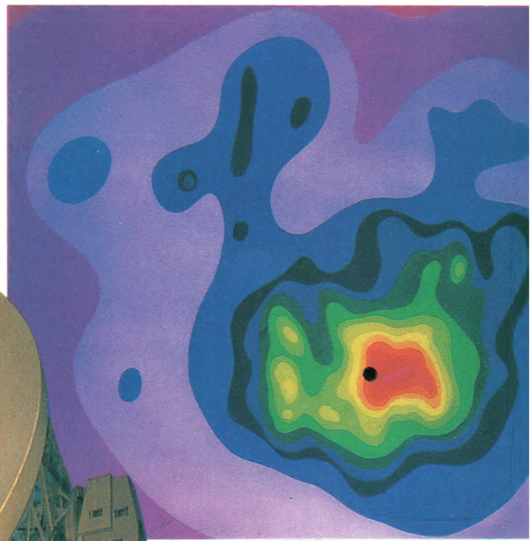
of them are around today depends on how long each one lasts.

For example, if civilizations destroy themselves rapidly by nuclear war or pollution – as we may be in danger of doing – then there may be no one else around at present for us to communicate with. However if civilizations expand into Space, they may continue for very long periods of time. If so, the Galaxy could be teeming with advanced life-forms. Although, if that is the case, it is strange that as yet we have found no sign of them.

Our Earth is the third planet outwards from the Sun. We are fortunate that it is at just the right distance from the Sun for liquid water to exist. If it were closer to the Sun, it would be so hot that all the water would evaporate – as on Venus. If it were farther away, our planet would freeze. The most distant planets from the Sun – Jupiter, Saturn, Uranus, Neptune and Pluto – are unable to support life for this reason.

In 1976, two US Space probes, Viking 1 and 2, landed on the red

Dr K Milne/David Parker/Science Photo Library



David Parker/Science Photo Library

***The pulsar** (black dot) on this radio image represents the core of a star that exploded about 11,000 years ago. It spins 13 times per second, emitting light and radio waves. The coloured bands indicate emissions from the still expanding shell of gas and dust.*

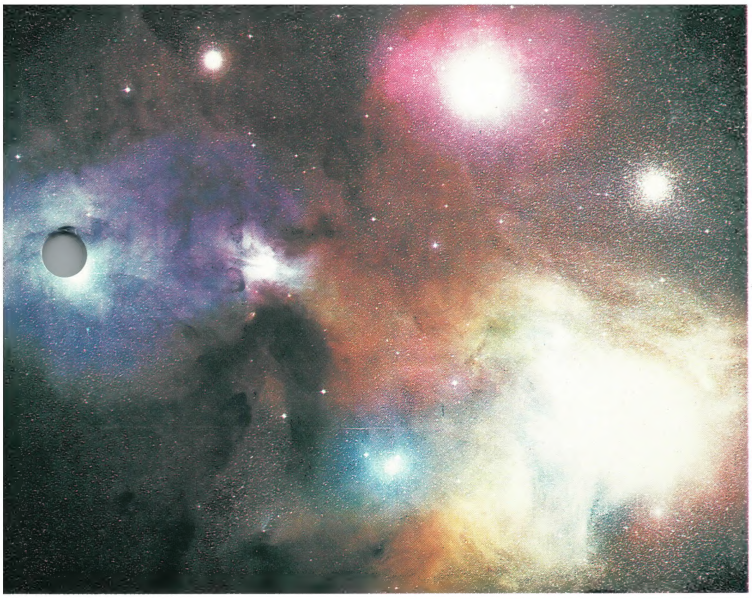
sands of the planet Mars to search for life. Mars is the fourth planet outwards from the Sun after our Earth. No life was found.

Planetary systems

If we are to find life, therefore, it must be on planets going around other stars. At present, astronomers have still to confirm that other planetary systems do exist. The stars are so far away that a planet going around even the nearest of them is too faint to see directly through a telescope. However, astronomers have found that some nearby stars are wobbling slightly in position – apparently because one or more large planets are orbiting them.

Dust clouds

Perhaps the most impressive evidence for the existence of other planetary systems was found in 1983 when the Infra-Red Astronomy Satellite, IRAS, detected clouds of dust around more than 40 stars.



Royal Observatory, Edinburgh & Anglo-Australian Telescope Board

The Scorpius – Ophiuchus nebula *is one of the most colourful regions of the sky. Bright stars light up the surrounding clouds of gas and dust. To capture the contrasting colours of these clouds, astronomers at the UK Schmidt Telescope, in Australia, took three separate black and white photographs through different colour filters and combined them.*

NORTHERN LIGHTS

ZEFA

Coloured lights in the night sky can be seen at high latitudes in both the northern and southern hemispheres. This photograph, taken above Lappland, is of the aurora borealis (also called the northern lights). Energetic particles from the Sun are attracted to the poles by the Earth's magnetic force. On entering the Earth's atmosphere they collide with air molecules, creating a halo of glowing light.

These clouds are thought to be planetary systems in the process of formation. One such cloud, around the star Beta Pictoris, was photographed in 1984. Our own planetary system is thought to have formed from such a cloud around the Sun 4,500 million years ago.

We cannot, as yet, travel to the stars as they are too far away, although scientific advances in the future may make some form of interstellar travel possible. But even if something similar to television's *Star Trek* does come true, it will still be easier to send radio signals between stars than to send people.

Pulsars

Radio signals travel at the speed of light, but since stars are so far apart it takes many years for a signal to travel from one star to another. In 1967, radio astronomers at Cambridge, UK, thought they had stumbled across an alien transmission when they detected radio pulses coming from a small area of sky. What they had actually discovered was a pulsar – an exceptionally small and dense star that spins very rapidly, sending out radio pulses as it does so.

Receiving signals

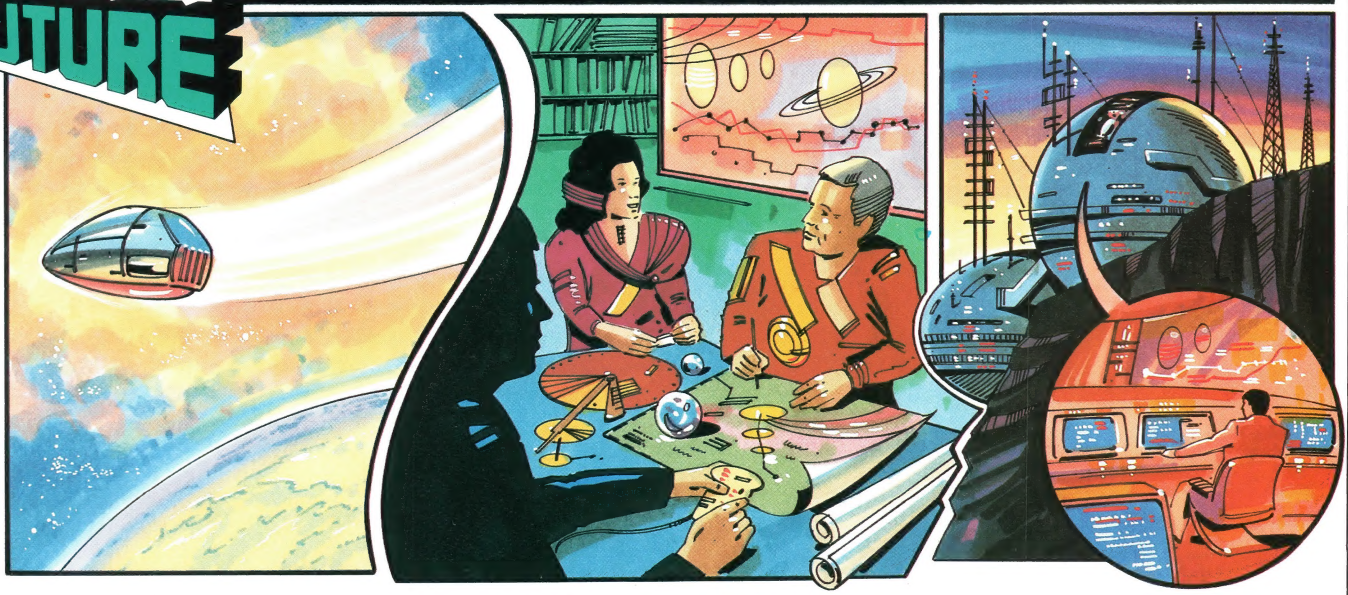
One clue to the fact that pulsars are natural objects is that they emitted at a wide range of frequencies. An artificial signal, as sent by a radio telescope, would be of one specific frequency – like that of a radio station emitting on a specific channel. However, there is an immense range of radio frequencies to choose from, which makes the task of finding any incoming signal very difficult.

Scientists in the United States have built receivers capable of tuning in to eight million channels at a time. This helps to cut down the search time at each star, but there is still an immense number of stars to search for evidence that someone out there is signalling to us.

If we do hear a signal, it will most likely come in the form of a series of pulses that can be assembled into a picture. Pictures are easy ways of sending large amounts of information without the need for written language. Even if we could not understand an incoming message, its very existence would tell us what we have long hoped to find – that we are not the only civilization in Space.

INTO THE FUTURE

TRAVELLING THROUGH TIME



Joe Lawrence

▲ *Because the distances between stars and planets in Space are so vast, perhaps the only way to find life on other planets is by travelling through time.*

▲ *Time travellers would be like early Earth explorers – mapping new territories in both Space and time, to build up a picture of our Universe and perhaps those beyond.*

▲ *Advanced communications – capable of transmitting and receiving across the dimension of time – could keep explorers in touch with Earth in the present day.*

Most sightings of Unidentified Flying Objects (UFOs) are cases of mistaken identity. Over 90 per cent of reports, when investigated, turn out to have been caused by natural or man-made objects. The main culprits include bright stars and planets, shooting stars, aeroplanes and orbiting satellites. Some cases are undoubtedly hoaxes. Despite careful investigation of UFO reports over many years, no alien spaceships have been scientifically identified.

Aetherius Society

Over 100,000 people *claim to have seen UFOs in the last 30 years. There are reports from every country in the world – an average of 40 sightings per day. This photograph was taken in England in 1978.*

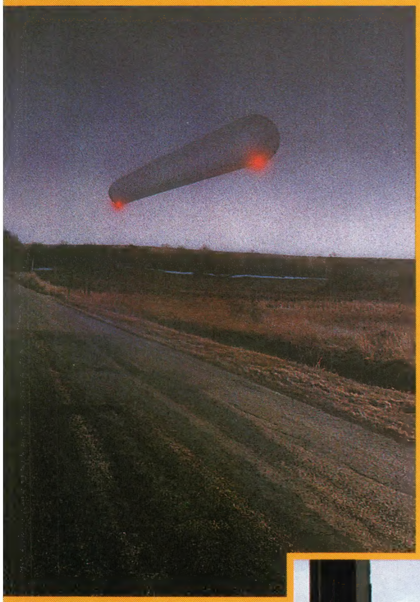
Ella Louise Fortune/Fortean Picture Library

This UFO *was photographed hovering over New Mexico in 1957.*

Hannah McRoberts/Fortean Picture Library

This detail *is part of a larger photograph, taken in 1981, of a mountain on Vancouver Island in Canada. Neither the photographer nor her companions saw the UFO at the time. The UFO appeared later when the film was developed.*

Illinois Air-Traffic Control *verified the presence of an unidentified object in the vicinity of several claimed sightings of this cylindrical object (an artist's impression) in the USA in 1987.*



Julian Baum/Science Photo Library

Fortean Picture Library

A triad of UFOs *captured on film in 1966. But experts are sceptical – the UFOs are out of focus, yet other details are clear.*

Stephen Pratt/Fortean Picture Library

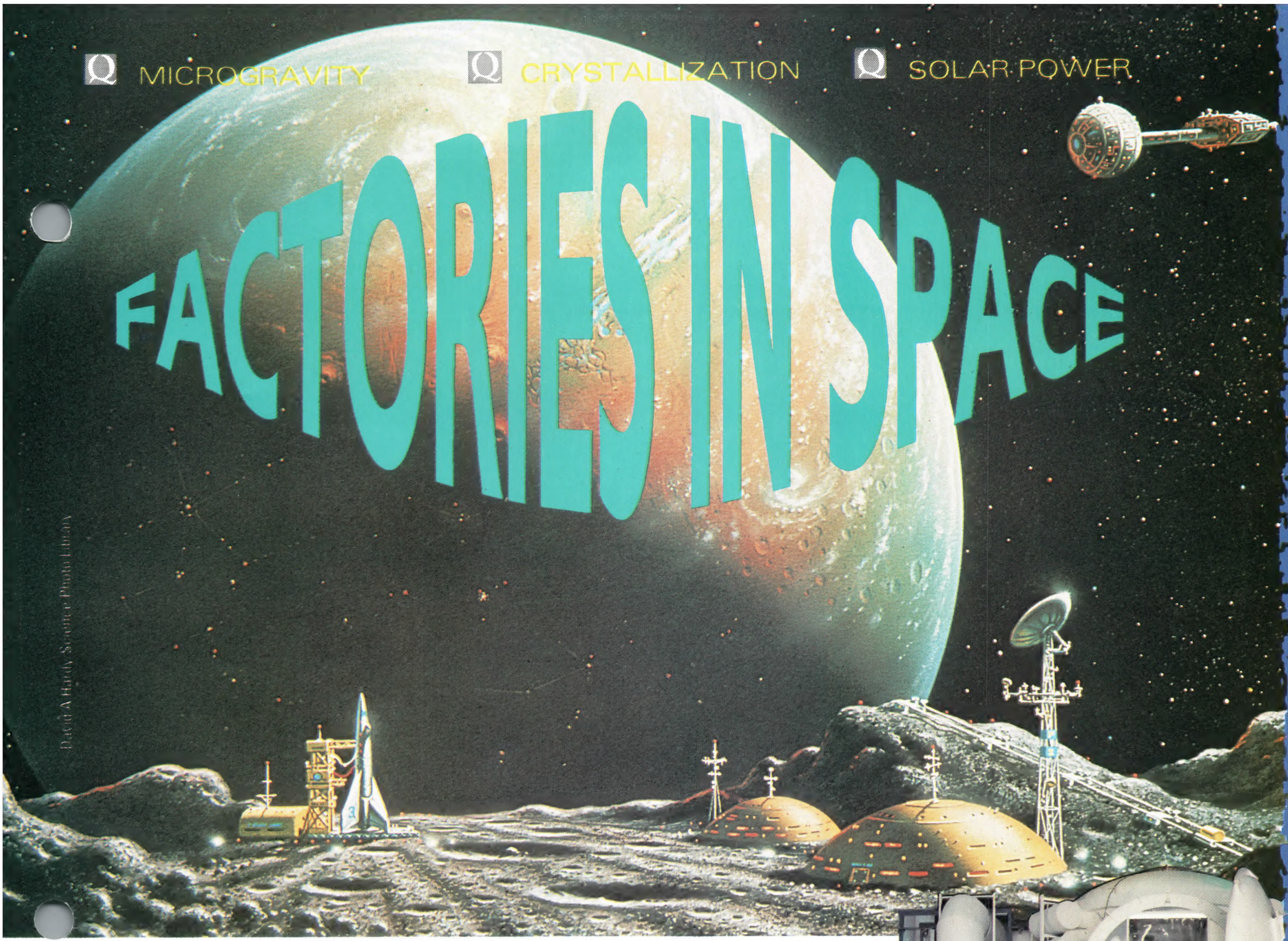
The reflection *of a ceiling light on the inside of a window shows how easily a fake UFO picture might be produced.*

Robert Harding Picture Library

A rare formation *of lenticular (lens-shaped) clouds might explain this sighting.*

MICROGRAVITY CRYSTALLIZATION SOLAR POWER

FACTORIES IN SPACE



David A Hardy, Science Photo Library

Space factories *might one day be built on the Moon. Metals, such as aluminium, could be extracted from the lunar rock.*

NASA

NASA *is developing self-contained, life-support chambers for use as orbiting research laboratories.*

GIANT ORBITING FACTORIES could become a reality some time in the next century. Materials that are difficult or impossible to produce on Earth might be more easily manufactured in the near-weightless conditions of Space.

The reason why some scientists are looking to Space as a possible industrial base is because gravity interferes with certain manufacturing processes on Earth. It hinders, for instance, the thorough mixing of substances that have different weights because it tends to make heavier materials sink. Large, perfect crystals can also be hard to grow on Earth because of the effects of gravity. Orbiting factories may offer the ideal solution.

Free-fall

A spacecraft in orbit is actually falling all the time, but it falls at exactly the same rate as the Earth's surface curves away from it below. As a result, it never gets closer to the ground. Instead, the spacecraft and everything in it are in a perpetual state of free-fall and weightlessness.

Strictly speaking, there are slight gravitational forces present caused by changes in the spacecraft's motion. Scientists, therefore, use the term *microgravity* rather than zero-gravity to describe the conditions in an orbiting spacecraft.

To build the next generation of super-fast computers, scientists are experimenting with new substances that allow electricity to pass through them at high speed. These substances, such as gallium arsenide and mercury cadmium telluride, must first be crystallized in a very pure and uniform way. On Earth, however, gravity interferes with this process, causing the crystals to grow unevenly. In Space, as tests aboard the Space Shuttle have already shown, crystals grow bigger, purer–and faster.

Protein crystals

Other experiments, carried out during NASA's Shuttle flights, have involved growing various types of protein crystal. Proteins are highly complex substances vital to the functioning of the human body and all living organisms. If scientists knew more about them, this could help in the development of new drugs for treating diseases such as cancer.

Orbiting factories might also be able to produce better quality audio and video tapes. This involves lining up the metal particles in the magnetic coating of the tape vertically rather than horizontally, thus increasing the recording density. Ball-bearings,and lenses are also greatly improved when manufactured in Space.

Carrying out research is one thing,

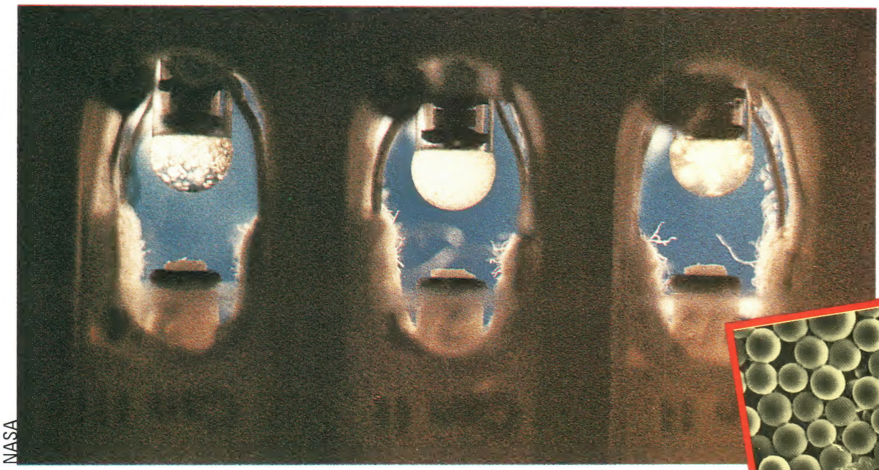
but developing a full-blown manufacturing industry in Space is another. Transporting materials to and from orbit is very expensive. And, in some cases, by the time an orbiting factory has been set up, industrial processing methods might have been improved on Earth. The American aerospace firm McDonnell Douglas, for instance, abandoned its research programme on the Shuttle because of improvements in ground-based technology. Some companies, on the other hand, are now stepping up their experiments in microgravity.

Much of the research into Space factories will be carried out in orbiting space stations, where astronauts will be able to conduct long-term experiments impossible to perform on short Shuttle flights.

The next stage is likely to be

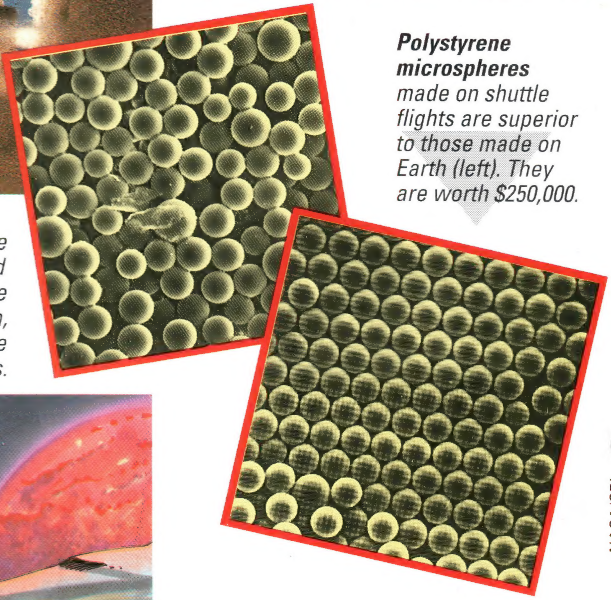
TOYS IN SPACE

On 12 April 1985, the Space shuttle Discovery transported 11 familiar toys such as yo-yos, spinning tops and jacks into the weightlessness of space. The crew then experimented to see how the toys would behave in their new environment. A gyroscope, for example, kept on spinning much longer than on Earth because it did not lose energy through wobbling. Magnetic marbles proved interesting, too. They stuck together in floating chains that wiggled back and forth. When enough marbles were added, the two ends of the chain linked up to make a circle. A slinky, on the other hand, was unable to do its familiar 'walk' without the pull of gravity.



NASA

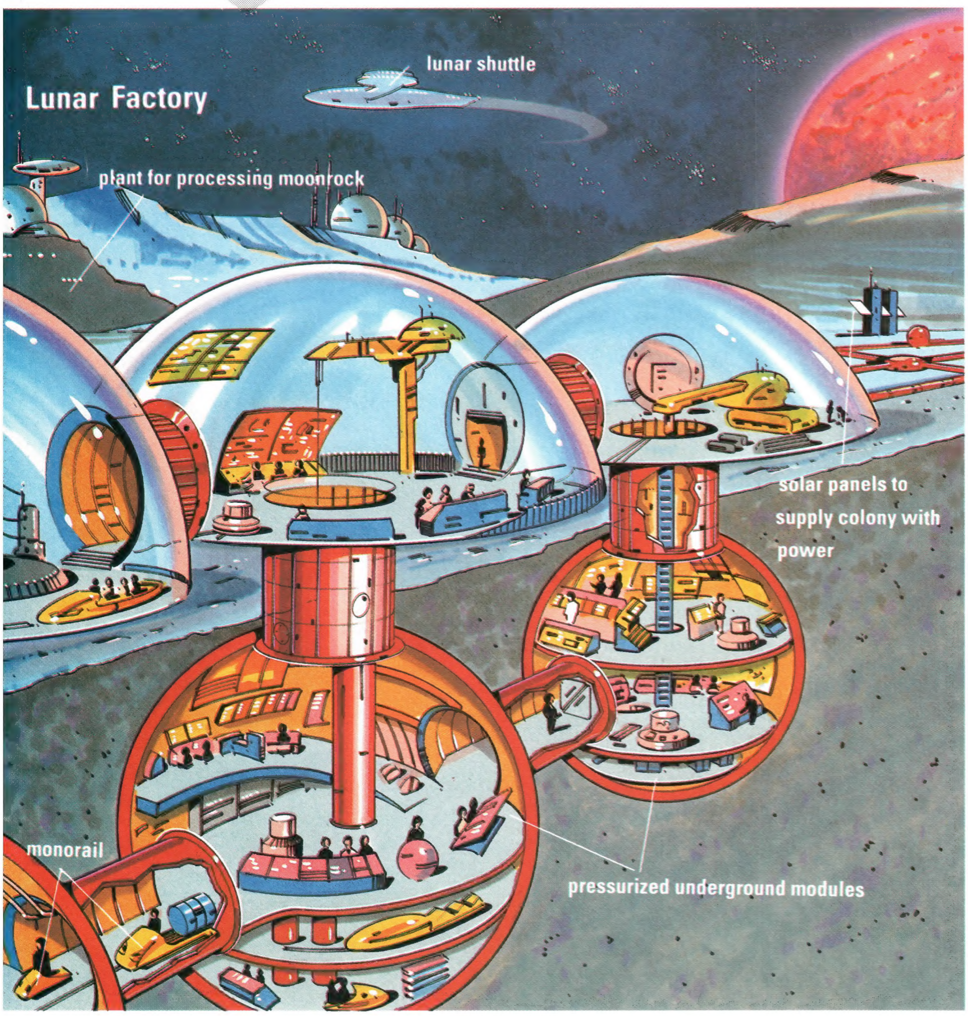
***Protein crystals**, grown in the weightless conditions on board the US Space Shuttle, are perfectly formed. On Earth, gravity causes defects in the size and shape of the crystals.*



NASA/SPL

***Polystyrene microspheres** made on shuttle flights are superior to those made on Earth (left). They are worth $250,000.*

***A lunar base** would be built from prefabricated modules made on Earth. Living quarters would be situated underground to provide both radiation shielding and thermal insulation.*



Joe Lawrence

the commencement of manufacturing certain materials on a small scale. Projecting even further into the future, orbiting solar power stations could provide the energy needed to run full scale manufacturing plants.

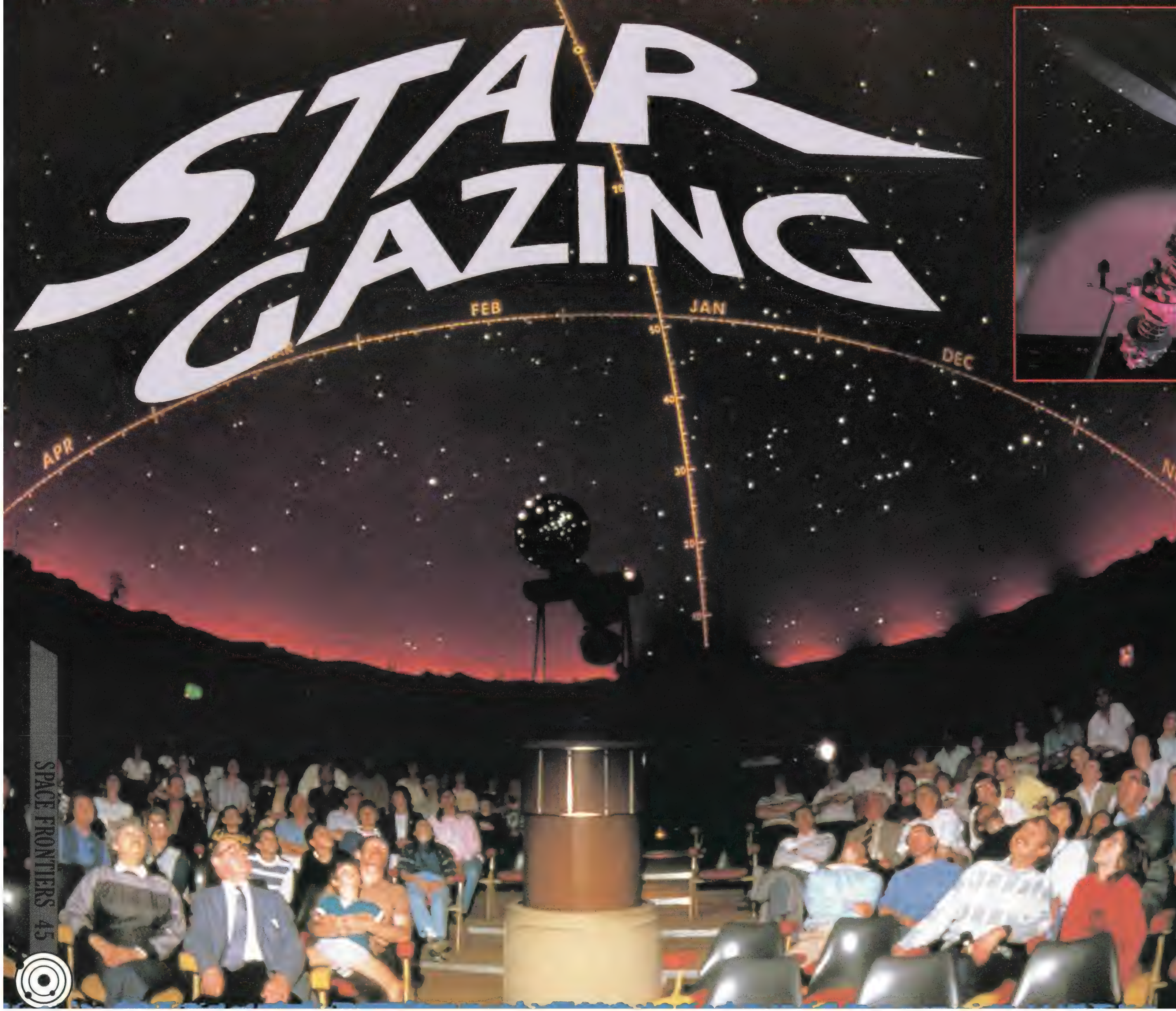
Just amazing!

POO!

SHUTTLE ASTRONAUTS HAD TO COPE WITH A NEW SPACE HAZARD – FLOATING RAT FOOD AND MONKEY DROPPINGS FROM THE CAGES OF ANIMALS UNDERGOING TESTS!

Paul Raymonde

STAR GAZING



American Museum-Hayden Planetarium

TAKE YOUR SEAT, LOOK UP, and you can see all the stars and planets in the night sky. In this case the sky is a smooth, domed ceiling and the stars are images created by a special projector. You are in a planetarium.

In just a few minutes, the planetarium projector can show motions that would otherwise take many hours, days, or even years to observe.

The night sky

A typical planetarium projector consists of two moveable globes fitted to either end of a cylinder that is supported by a metal framework. One globe projects stars visible from the northern hemisphere, while the other projects stars visible from the southern hemisphere.

David Parker/Science Photo Library

***Special effects** thrill planetarium audiences with close-ups of exploding stars, alien landscapes and travelling spacecraft. The projector (above) is often part of the show.*

As many as 16 fixed projectors in each globe, illuminated by a central lamp, cast images of several thousand stars on to the dome. As the globe turns it simulates the movement of the constellations across the sky caused by the Earth's rotation.

The stars remain in the same position relative to one another. But the Sun, Moon and planets move against the starry background. Because of this, separate projectors are needed for each of these objects. The variable projectors are located on the framework between the star globes. Like the globes, they are moved by motors and precision gear systems.

HEAVEN IN A BOX

With the advent of powerful personal computers, maps of the stars and planets can now be viewed at home. A variety of night sky programmes are available for micros. To set up such a programme, the user simply enters the time, date, and location from which he or she wishes to view. The software then calculates the corresponding position in the sky of the stars, planets, Sun, and Moon and displays the results on the monitor screen.

Time travel

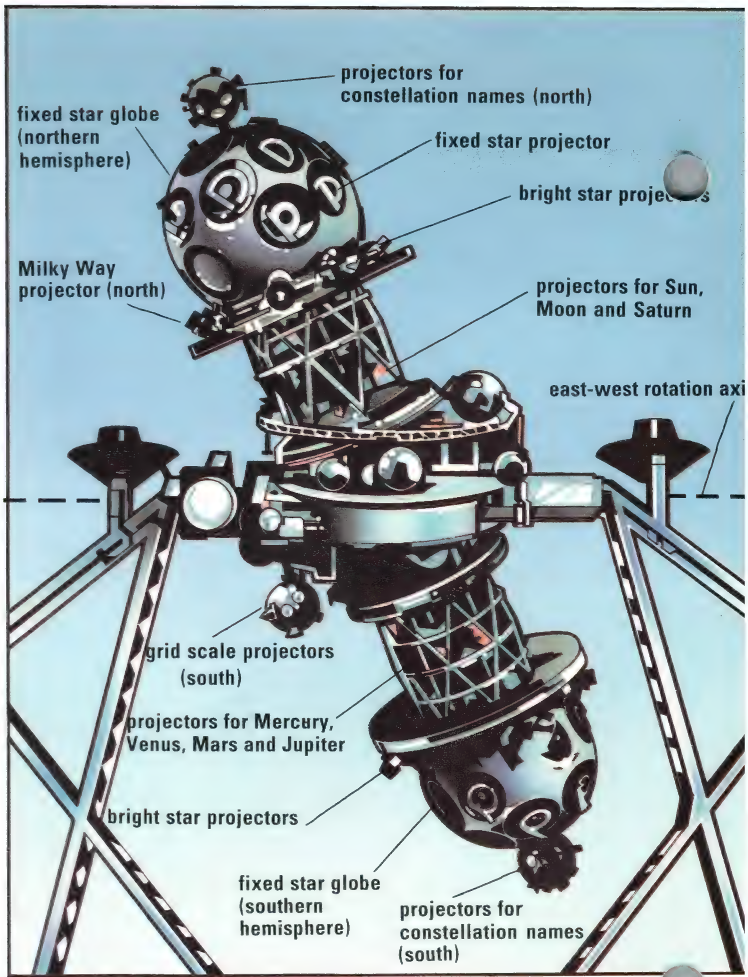
From a central console, the projector is controlled to show any part of the sky at any time in the past, present, or future. It can track the movement of stars throughout a single night, the movement of planets throughout a whole year, or the changing appearance of the sky over a much longer period of time. For example, the Earth's axis does not remain pointing in the same direction in Space. It wobbles like a spinning top. One wobble takes 25,800 years to complete (the period of precession). This enormous time-span can be compressed into just a few minutes in the planetarium.

One of the largest projector types is the Zeiss instrument at the London Planetarium. Measuring 4 metres in length, it weighs over 2,000 kg and contains some 29,000 individual parts. The Sun, Moon, planets and brightest stars in the sky are represented by individual projectors. Further projectors display the Milky Way, the names of the constellations, and a grid for measuring star positions in the sky.

Multi-media show

Many planetariums create special effects to compliment their sky shows. These include pre-recorded voice commentary and music, and superimposed still images from slide and motion picture projectors. The result is an impressive multi-media presentation that both entertains and informs the audience.

Increasingly, television projection systems are replacing the earlier optical-mechanical projectors. These new, electronic systems, linked to computers, take audiences on imaginary high-speed journeys through interstellar Space, showing the heavens from perspectives other than the Earth's surface; for example from the Moon, Mars or Venus.



The Zeiss planetarium projector *has 16 small projectors on either globe – each with its own optical system. Most projectors move about three axes to allow observation from any latitude on Earth, at any time of day and at any era in time.*

Paul Desmond

Galaxies *viewed from inside the stone circle at Stonehenge, UK. By turning a projector on its east-west axis, the sky can be seen from anywhere on Earth. At the North Pole stars appear to circle overhead without rising or setting. Stars over the southern hemisphere appear unfamiliar to inhabitants of the northern hemisphere and vice-versa.*

London Planetarium

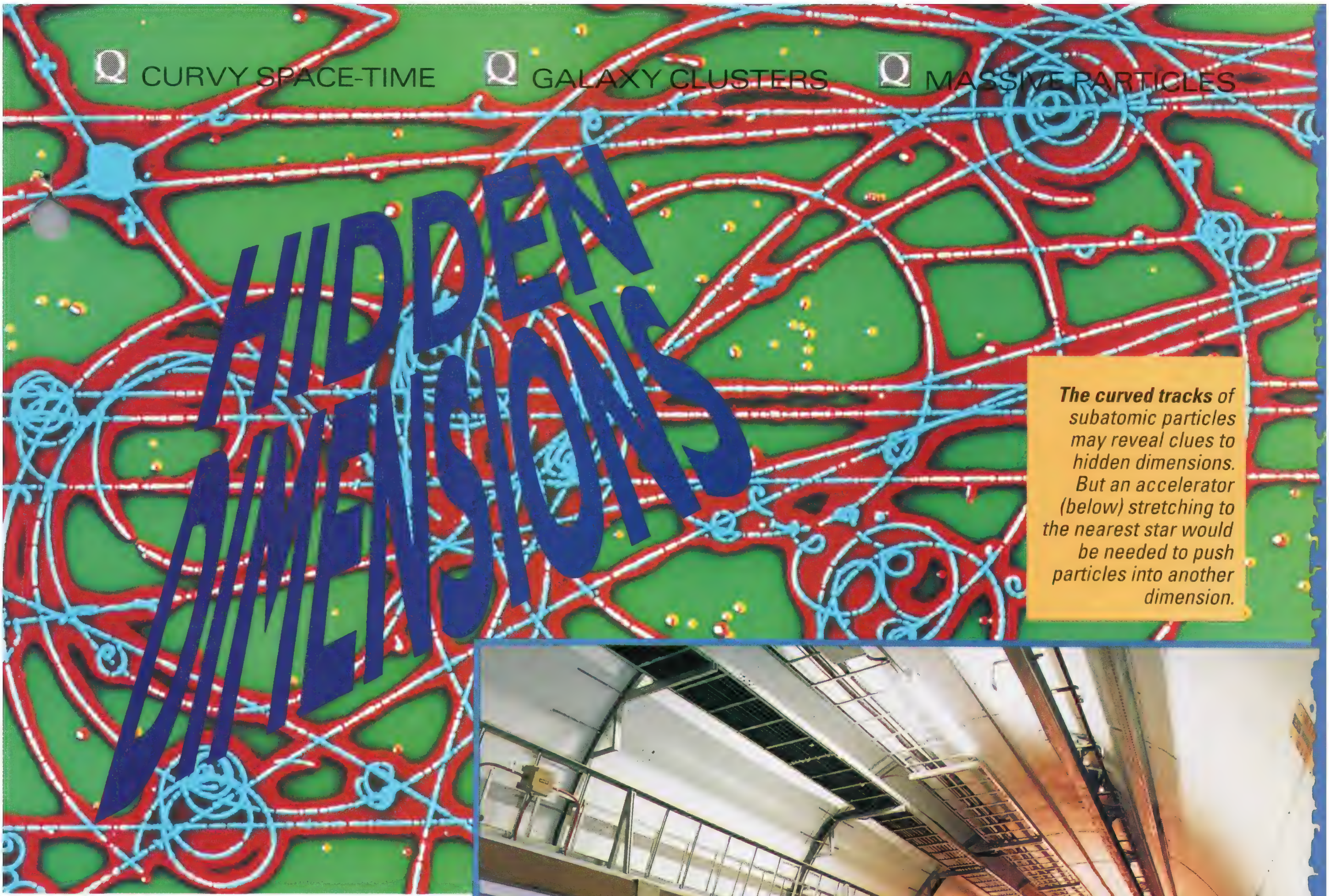
Just amazing!

SPEED READING

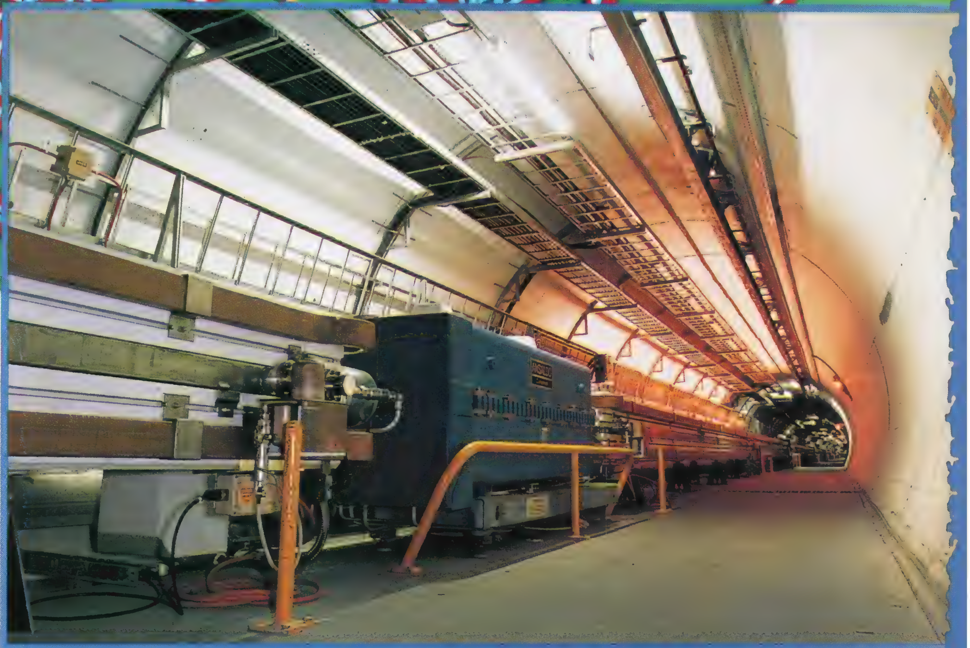
THE EARTH MOVES AROUND THE SUN AT OVER 1,600 KM PER MINUTE. WHILE READING THIS PAGE YOU WILL HAVE TRAVELLED SEVERAL HUNDRED KILOMETRES THROUGH SPACE.

Paul Raymonde

HIDDEN DIMENSIONS



The curved tracks of subatomic particles may reveal clues to hidden dimensions. But an accelerator (below) stretching to the nearest star would be needed to push particles into another dimension.



Patrice Loiez/CERN/Science Photo Library

David Parker/Science Photo Library

THE EVERYDAY WORLD WE live in has three dimensions. It has height, width and depth. But it is quite possible to imagine what it must be like to live in a world with a different number of dimensions – and it can be quite useful too.

In a one-dimensional world, you would be at a point that was confined to a line. You could move up and down it, but you would have no direct knowledge of anything outside that line. To define your position in this one-dimensional world all you would need is one number saying how far along the line you were from a reference point. Once you had picked a reference point on the line you could define where you were by saying that you were 5 cm or 10 cm from that point. If you were 5 cm or 10 cm down the line, on the other side of the reference point (which you would mark as 0, as it was 0 cm from itself), your position would be defined as -5 cm or -10 cm from the reference point.

In two dimensions

However, a one-dimensional being may infer that a second dimension exists, if he was living on a loop, for example. If he headed off in one direction and some time later ended up back where he started, this could only be explained by a hitherto unobserved dimension.

If you lived in a two-dimensional world, you would live in a world with area but without thickness, like the people in a picture. Both paper cutouts lying flat on a table top and shadows on a wall inhabit a two-dimensional world.

Defining your position

To define where you were in this world, you would need two numbers. You could say that you were 4.62 cm east and 3.89 cm north of a particular reference point. In this world you could wander about, but you would not be able to tie knots or jump in the air as these things would require a third dimension.

A being from this two-dimensional world – a 'Flatlander' – would not be not be able to see a third dimension but might be able to infer one if he lived on the surface of a sphere, for example. If four intrepid Flatlanders set off in four different directions at the same speed, they would all meet at a point on the opposite side of the sphere. This could only be explained by an unobserved third dimension.

In our world, a sailor, for example, can define his position by just two numbers – a latitude and a longitude – that fixes his position only because he must be on the surface of the Earth. However, it could be said that we really live in a four-dimensional world. For an airline pilot to define precisely where he is, he has to give the time and date as well as his latitude and longitude. The time – and date, which is only a larger measure of time, the number of years, months and days since the birth of Christ – can be considered as a fourth dimension.

Bending light beams

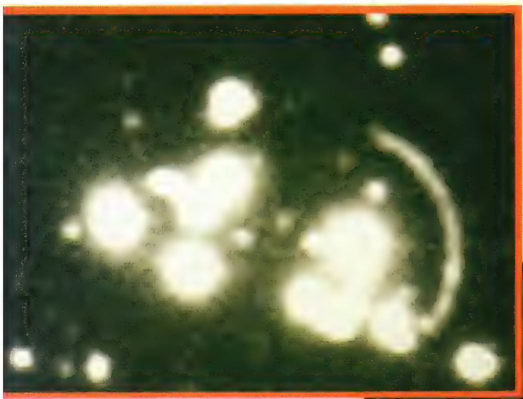
Physicist Albert Einstein discovered that if you treat time as a fourth dimension, gravity will be a curve in four-dimensional space-time. Light was once thought not to be affected by a gravitational field, but in 1919 it was discovered that light from distant stars is bent around the curve in

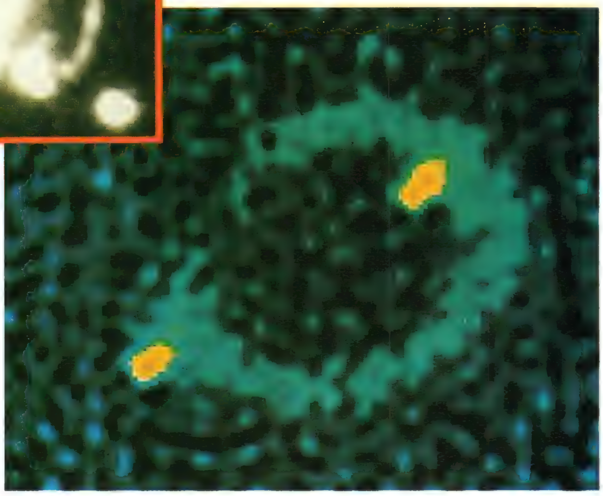
space-time caused by the gravitational pull of the Sun – showing Einstein's theory to be correct.

Soon after, Soviet physicist Theodor Kaluza showed that if there were five dimensions, then gravity and electromagnetism would be manifestations of a single force. Since then, mathematicians have worked out that all the known forces – gravity, electromagnetism and the so-called strong and weak forces that operate inside the atomic nucleus – are in fact a single force. The key to this, however, is that there must be 11 dimensions.

The problem then is to explain why we are aware of only four of them. Scientists have suggested that there were perhaps 11 dimensions when the Universe was born. But an inconceivably short time after the 'Big Bang', when matter, energy and space-time itself were created, seven of the dimensions 'curled up' and they all but disappeared as the Universe expanded and cooled. But they are still present, forming an unperceived universe 'next door' to our own.

NOAO/Science Photo Library





NRAO/AUI/Science Photo Library

The huge gravitational pull of a galaxy deforms four-dimensional space-time. This force creates a massive 'gravitational lens' in Space that spreads light or radio waves from a single source into an arc or a full 'Einstein ring' (right).

Into new dimensions

We can see dimensions 'curl up' in the real world. If a ball is viewed close up, you can see its ball-like structure – it has three dimensions. But if it is viewed from a great distance, it looks like a point which has no dimensions.

A subatomic particle could, in principle, enter the extra dimensions, seeming to vanish from our world for an instant, and then quickly return. But fantastically high energies would be needed to push a particle into another dimension. With present technology, you would need a particle accelerator several light years across – stretching, say, from here to the nearest star.

The Big Bang

But back at the time of the Big Bang, when these energies would have been available and switching between the extra dimensions would have been easy, particles 1,019 times the mass of a proton – which is still only around 1/100,000th of a gram – would have been created.

Some of these so-called 'massive' particles might still exist today and scientists throughout the world are looking for them. The discovery of such particles would reveal the existence of the hidden dimensions.

Just amazing!

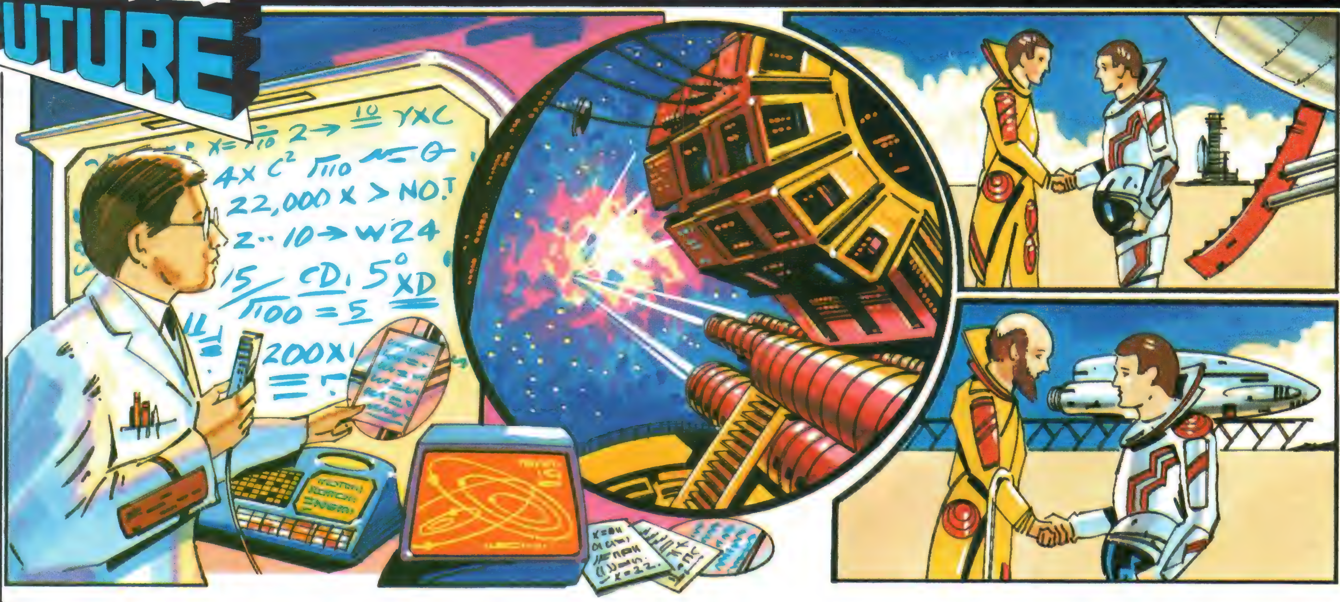
GUN HO

IF YOU COULD SHOOT A BULLET AT 64,000 KM/H AT THE NORTH POLE, ABOUT HALF AN HOUR LATER IT WOULD HIT YOU IN THE BAACK OF THE HEAD.

Paul Raymonde

INTO THE FUTURE

THE KEY TO TIME TRAVEL



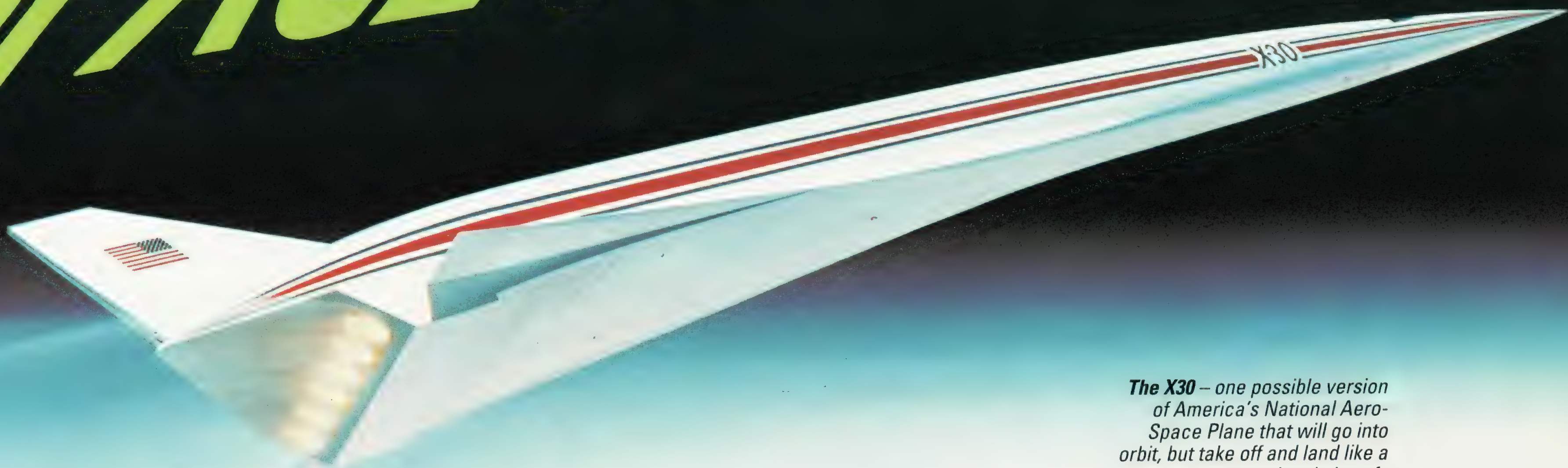
▲ *Although it is impossible to travel back in time, scientists have calculated the strange, time-warping effects of travelling at speeds close to that of light.*

▲ *If a spaceship were to travel at 99.9 per cent of the speed of light, time for the astronauts on board would run over 20 times slower than time on Earth.*

▲ *If they returned after what was, to them, a one-year flight, an astronaut would find that his twin brother had aged by more than 20 years.*

Joe Lawrence

SPACE PLANES



The X30 *– one possible version of America's National Aero-Space Plane that will go into orbit, but take off and land like a conventional aircraft.*

DOD/Science Photo Library

NEXT CENTURY, SPACECRAFT will take off from a runway like ordinary aircraft, accelerate to a speed of about 29,000 km/h and then climb into the rarified atmosphere of Space over 150 kilometres above the surface of the Earth.

The idea for a Space plane goes back over 30 years, but the race into Space led to massive rockets being used to power launch vehicles instead. At that time, experimental Space planes that were carried to the edge of the atmosphere by massive bombers were abandoned. Both the United States and Russia have developed Space shuttles that can land like a plane. So far, though, no one has built a vehicle that can fly up to Earth orbit without the help of large rocket boosters, but there are several Space plane designs now in an advanced stage of development.

America's plans

Plans for America's National Aero-Space Plane (NASP) show a sleek, wedge-shaped craft 50 metres long – 9 metres longer than the Space Shuttle. Four different types of engine slung under the wings and fuselage will propel the Space plane to its final speed of 25 times the speed of sound, or Mach 25.

To take off and accelerate up to Mach 2 – about 2,250 km/h – the NASP will use turbojet engines similar to those aboard large passenger airliners. The NASP turbojets have a spinning fan at the front to suck air into a combustion chamber and compress it. Once inside the combustion chamber, the air is mixed with hydrogen fuel and ignited. As the hot exhaust gas escapes from the back of the turbojet, it produces a forward thrust and turns a second set of blades that drive the front turbine.

Ramjets take over

Above Mach 2, the oncoming air will be moving so fast that it will compress itself, making the turbojet's spinning blades more of a hindrance than a help. At this stage, the turbojets are shut down and a second set of engines, known as ramjets, allowed to take over.

Ramjets are like turbojets without turbines. As the Space plane moves quickly forward, air rushes into the front opening of the ramjet and 'rams' itself, at high pressure, into the combustion chamber. The increased rate at which air is gulped in by the fast-moving plane will offset the fact that oxygen is more rarefied at these higher altitudes.

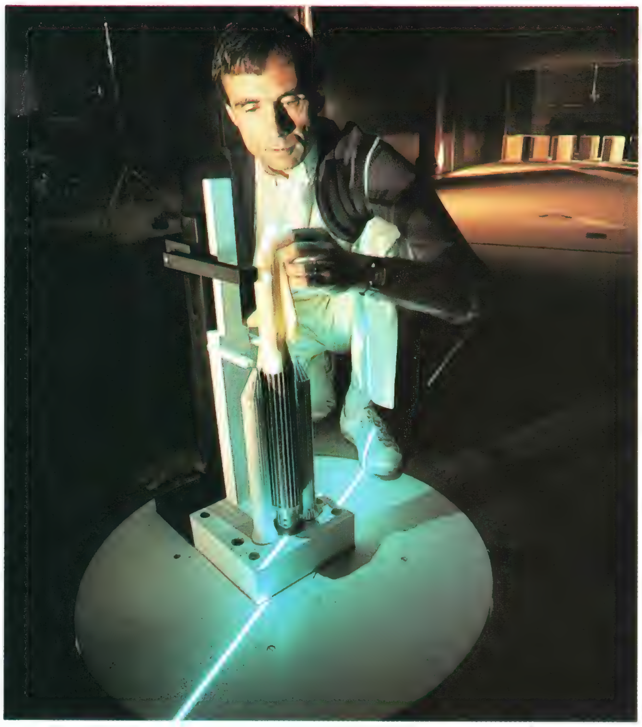
Scramjets

The NASP's ramjets will continue working up to a speed of between Mach 6 and Mach 8 (between 6,750 and 9,000 km/h). Above Mach 8, air molecules can break apart as they enter the engine, using up energy that could otherwise be used to power the Space plane. So, a third set of engines, called scramjets – or supersonic combustion ramjets – will kick in. These channel the air through narrow internal ducts that prevent the molecules breaking apart.

Scramjets will take the Space plane to Mach 20 – and to the edge of Space. At that point the air runs out, so regular liquid hydrogen and liquid oxygen fuelled rocket engines take over, pushing the Space plane up to Mach 25 and out into orbit.

NASA

A computer simulation *of the air flow over the fuselage of a proposed design for a Space plane. This work is vital as a Space plane must be able to cope with air at the density and pressure of the atmosphere at ground level as well as the greatly reduced pressures that it will encounter on its way into Space.*



Philippe Plailly/Science Photo Library

A model of Hermes, *the European Space Shuttle, and its Ariane-5 rocket are put through wind tunnel tests. Magnesium powder shows air flow and blue-green laser light detects turbulence.*

Cooling systems

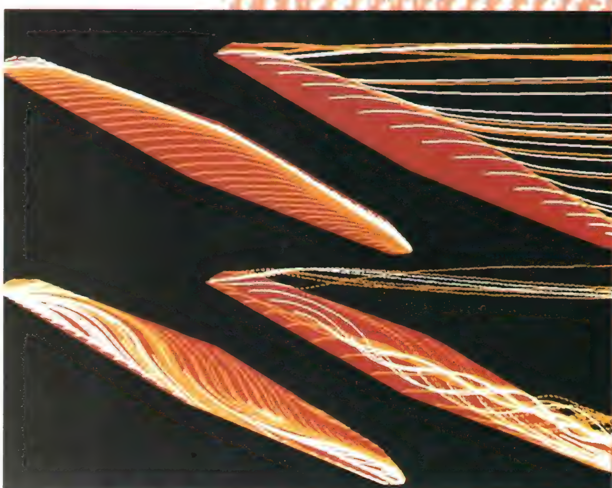
In the past, spacecraft have been protected, during their high-speed passage through the atmosphere, either by a conventional heat shield or – in the case of the Shuttle – a layer of thermal tiles. But the Space plane will need a more advanced method of staying cool. This is because – even though it is travelling a good deal slower than conventional rocket-mounted spacecraft – it will be subjected to frictional heating for much longer periods.

Flying most of the way into Space along a gentle, 15 to 20 degree incline, the NASP will pass through hundreds of kilometres of air at speeds of up to Mach 20. To protect the craft during these long, hot ascents, most of its external surfaces will be covered with light, heat-resistant titanium aluminide and carbon composites. These materials can withstand temperatures up to about 1,650°C.

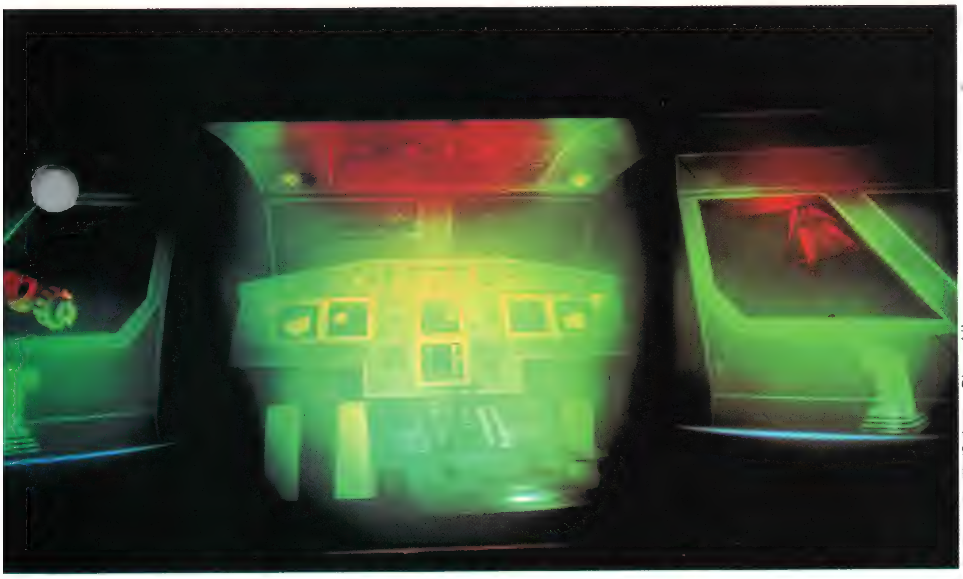
Certain parts of the Space plane, however, will get even hotter than this. Temperatures at leading edges,

SCREEN TESTS

The extensive use of computer simulation means that every modification of a design does not have to be built into a model and tested in a wind tunnel. Computer programs using simulations of air flows can be used to weed out impractical designs quickly, leaving only the most promising to go forward to expensive and time consuming wind tunnel tests. Here the airflow over a wing is modelled at different angles of attack. Once the wing configuration looks right on screen, it will be incorporated into the complete design. And when all the elements satisfy the simulation, the model builders get to work – to check that it is accurate



NASA



Philippe Plailly/Science Photo Library

***Flight deck** simulations of Hermes are made as holograms. Through the left-hand window, there is a Space station Hermes is about to dock with. Through the right, there is runway on Earth that Hermes is about to land on.*

such as the nose and front of the wings, may climb to between 2,200 and 2,750°C.

Heating the fuel

To protect these areas, a special copper alloy will be used. Beneath the hot spots, the liquid hydrogen fuel will circulate through pipes one five-thousandth of a millimetre wide. The liquid hydrogen fuel is stored at -253°C for safety reasons. But as it passes under the hot spots, it will pick up the heat from the copper alloy, turning the liquid hydrogen into a 800°C gas ready to be pumped into the engine combustion chambers. The heat picked up on the way saves engine power and will add as much as 10 per cent to the plane s speed.

One of the problems with today's Space Shuttle is that it takes several weeks to prepare for launch. This is because the orbiter has to be fitted to a large external fuel tank and two solid rocket boosters. Then the whole assembly has to be tediously rolled out to the launch pad on the back of a giant crawler transporter.

Ready for take-off

By contrast, a Space plane like the NASP would sit on the runway like a conventional plane and could be fueled up and made ready for take-off in a very short time. As a result, it could respond to life-threatening emergencies in Earth orbit, such as major equipment failure aboard a Space station or rescuing a dangerously ill member of the crew.

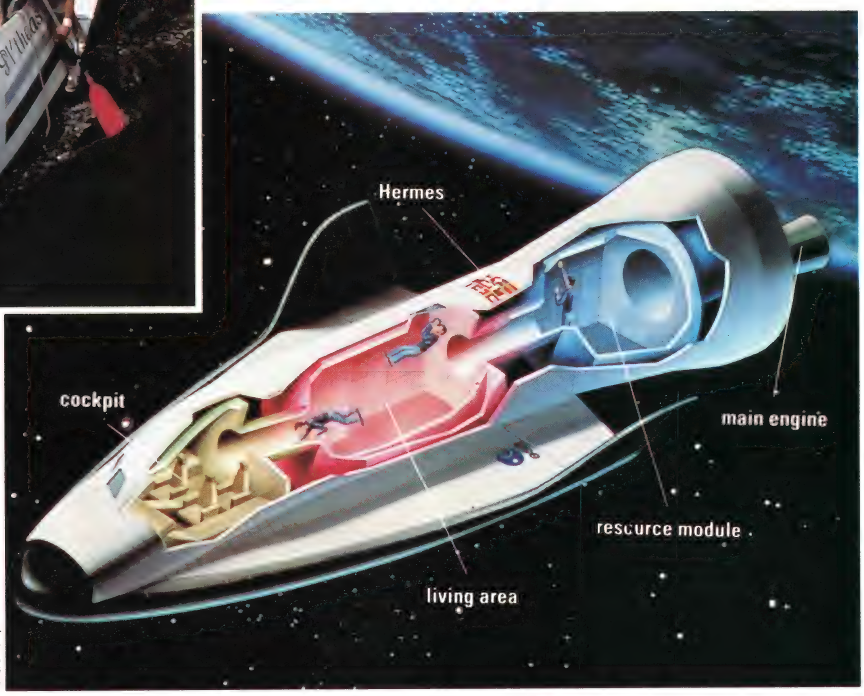
Within a few hours, the NASP could be launched on a rescue mission carrying spare parts, air and fuel

Gamma/Frank Spooner Pictures

***Accidents** can happen and every eventuality has to be planned for by Space plane designers. Hermes is tested to see if it can float, just in case its landing is aborted and it has to come down in the sea.*

Ducros/Jerrican

***Hermes** – the proposed European Space Shuttle – glides into land on a runway like the American Shuttle.*



Ducros/Jerrican

***Hermes' crew** of three will divide their time between the cockpit, a living area where they will work, and a resource module that will hold cargo and experiments and act as an air-lock for EVAs.*

***Sanger** – Germany's proposed Space plane – will use a large aeroplane as a 'mother ship' to carry the Space craft itself up to the edge of the Earth's atmosphere from where it will be launched into orbit.*

Gamma/Frank Spooner Pictures

or emergency medical gear, or even bringing a sick astronaut back to Earth for treatment.

Two-stage craft

Other countries are looking at the possibility of building Space planes. Germany has been planning a two-stage, re-usable craft called Sanger. The first stage of Sanger would be a 400-tonne, 52-metre-long, piloted mothership with a wingspan of 25 metres.

Powered by air-breathing jets that would use oxygen from the air to burn the fuel, it would fly to a height of 30 km and a speed of Mach 6. Then it would release the second stage, a 15-metre long, winged craft equipped with rocket engines that would blast it into orbit, while the mothership flew back to Earth. When its mission was completed, Sanger would glide back to Earth like the Space Shuttle.

France, meanwhile, is spearheading the development of the European Space Agency's three-man mini-shuttle, called Hermes. Though not a true Space plane in that it will be launched on top of an Ariane 5 booster rocket, Hermes too will glide back to Earth like an aircraft.

Four-in-one engines

Britain also began studies of a horizontal take-off and landing Space plane, known as HOTOL, which used a revolutionary design of engine that changed configuration from turbojet through ram- and scramjet to rocket engine as speed increased. However, lack of government support led to the project being cancelled by the British government, though funding is being sought from other sources.

Japan and Russia are the other principal nations involved in Space plane design. By early next century, it seems that the NASP and a few international rivals will have begun a new chapter in the history of Space exploration.

PEGASUS

Gamma/Frank Spooner Pictures

Early in 1990, a new type of launch vehicle, called Pegasus, made its maiden voyage into Space. It was carried to a height of about 12,000 metres slung underneath a B-52 bomber before completing its journey into orbit under its own rocket power.

The 18-tonne, 15-metre-long Pegasus looks like a missile with a pair of stubby wings. Packed into its fuselage are three stages, each with its own solid-fuel motor. These are capable of delivering small satellites, weighing up to 450 kilograms into a low orbital trajectory around the Earth. The use of a carrier plane should help Pegasus to halve the cost of a conventional launch as well as eliminate the risk involved in launching rockets at ground level near populated areas.

Just amazing!

THE ORIENT EXPRESS

THE US NATIONAL AERO-SPACE PLANE HAS BEEN NICKNAMED THE 'ORIENT EXPRESS' BECAUSE IT WILL SOMEDAY WHISK PASSENGERS BETWEEN NEW YORK AND TOKYO IN TWO HOURS!

Paul Raymonde

__The MD-2001__ – McDonnell Douglas's version of America's National Aero-Space Plane – will carry passengers from Washington to Beijing in two and a half hours. But it will also have military uses and is being developed in partnership with the US Navy and Air Force as well as NASA.

McDonnell Douglas/DOD

ASTRO NUTS AND BOLTS

SATELLITE REPAIR · ANCHORING · GRIPPING

NASA

***The remote manipulator arm**, the giant Canadian-built handling tool, on board the Shuttle. Here it is being used to deploy the Hubble telescope.*

CARRYING OUT REPAIRS and other tasks in Space calls for a wide variety of tools, from ordinary spanners to multi-million-dollar devices specially made for a particular mission.

Some of the most sophisticated tools have been developed to enable shuttle astronauts to capture and recover crippled orbiting satellites. In April 1984, the shuttle Challenger was launched with an assortment of special equipment aboard to help repair the damaged Solar Max satellite. After the shuttle had moved to within 60 metres of its target, Astronaut George Nelson used a Manned Manoeuvring Unit (MMU) to propel himself over the the faulty spacecraft.

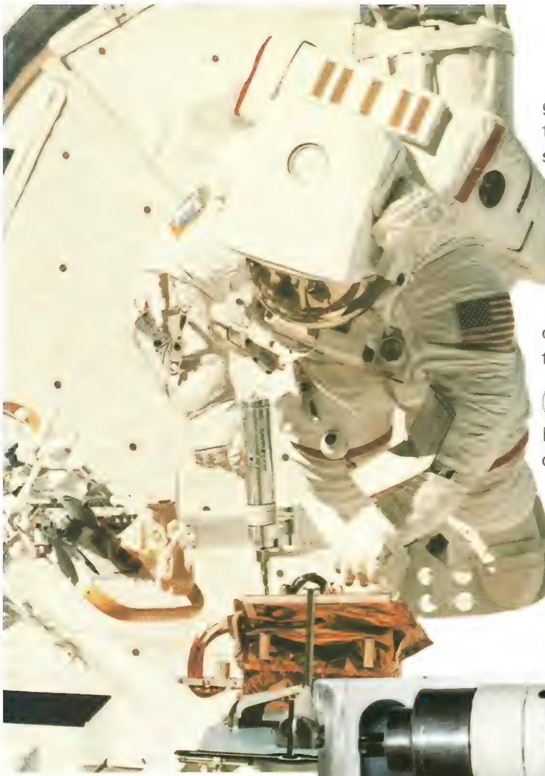
Locking on

Attached to the front of the MMU was a device called a T-Pad. With this, it was hoped that Nelson could lock on to a metal pin projecting from the side of the satellite and then use his MMU's thrusters to nudge Solar Max into the shuttle's payload bay.

Although, in the event, Nelson failed to attach the T-pad, another tool – the shuttle's robot arm – succeeded in catching hold of the satellite. With Solar Max safely in the payload bay, astronauts removed fasteners on the satellite's main electronics box using a special, battery-operated power tool,

NASA

***Astronaut Dale Gardner** captures a broken Westar VI communications satellite with a specially designed tool, the 'apogee kick motor capture device'. This jams in the nozzle of the Westar's spent engine, stabilizing the spinning satellite. Once it is under control the astronaut can manoeuvre it back into the Space Shuttle's cargo bay.*



NASA/Science Photo Library

***Bruce McCandless** using a special screwdriver (right) in the Shuttle's cargo bay. His feet are anchored by the mobile foot restraint on the manipulator arm.*

NASA

similar to a hand drill. Having replaced the broken module, they resealed the unit, and then hoisted the satellite back into orbit with the robot arm.

One of the biggest problems with using tools in Space is the lack of gravity. For example, if an astronaut tries to undo a nut using an ordinary spanner, he would rotate his entire body in the opposite direction.

There are two possible solutions. The first is to provide a means for astronauts to anchor themselves firmly before starting a job. The MMU is ideal for this because its thrusters fire automatically to hold it steady in position.

Anti-torque tools

Foot restraints, on both the inside and outside of spacecraft, can also hold an astronaut still while working in orbit. Another solution is to design new tools specifically for use in zero gravity. Anti-torque tools, for example, would counter any twisting force exerted by the astronaut with an equal and opposite force. So-called 'reactionless' tools balance out any pushes or pulls. In each case, the astronaut could use the tools without being made to spin or drift away. Studies have already been done on reactionless, mechanical hammers and saws, and a multi-purpose power tool that can act as a reversible drill. Other useful items in an orbital repair kit include a glove with rubbery pins on the surface for better gripping, a gluing tool and devices for cleaning up debris at the end of a job. In all cases, tools must be tethered to the astronaut's suit to prevent them from simply floating away into Space.

Maintenance

Fixing a satellite in orbit may be expensive, but it is much cheaper than building and launching a new one. For this reason, satellites in the future will be designed for easy maintenance and repair. Astronauts will use a range of standard tools to unplug faulty modules and replace them with new ones brought up from Earth.

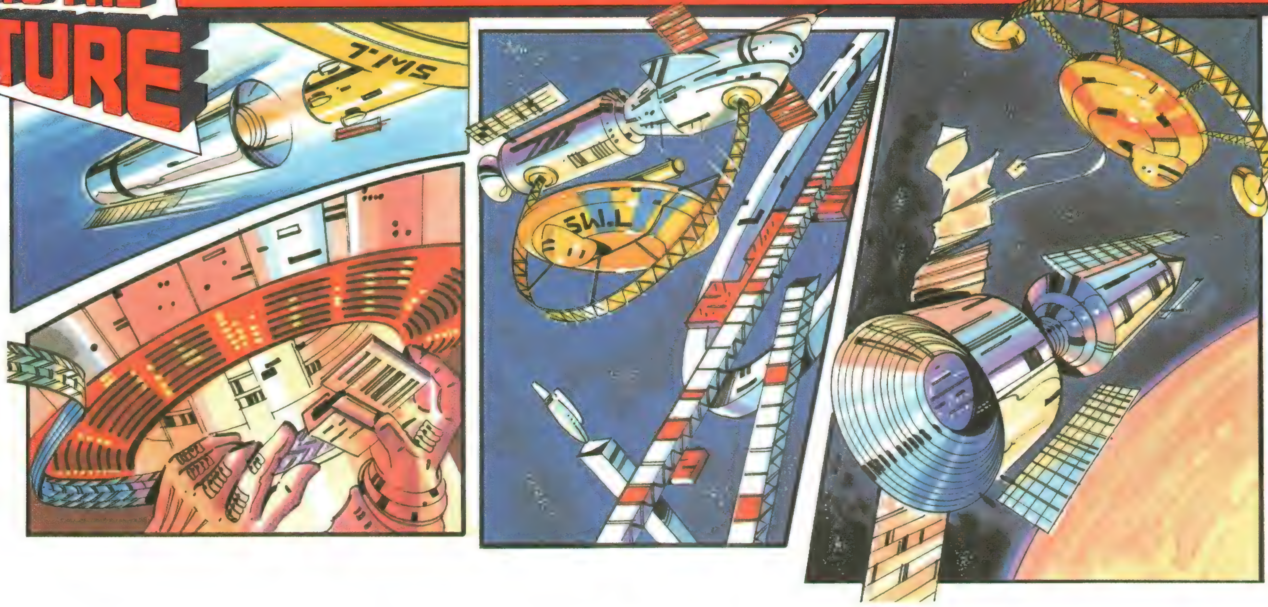
Just amazing!

EATIQUETTE

EVERYDAY TOOLS THAT WE TAKE FOR GRANTED ON EARTH – LIKE CUTLERY – HAVE NO PLACE IN SPACE. A SPOON, FOR EXAMPLE, IS USELESS IN ZERO-GRAVITY.

Paul Raymonde

INTO THE FUTURE — SATELLITE REPAIR



▲ *As fixing satellites or other spacecraft in orbit is much cheaper than building and launching new ones, they will be designed for easy maintenance and repair.*

▲ *Under remote control, a robot Space tug called a teleoperator manoeuvring system (TMS) will move a broken-down satellite, for example, to a Space station.*

▲ *At the Space station astronauts will unplug faulty modules and replace them with new ones from Earth. The TMS then returns the satellite to its original orbit.*

Joe Lawrence

NUCLEAR CORE SUN SPOTS CORONA

THE MIGHTY SUN

Tony Stone Photo Library, London

IF THE NUCLEAR FURNACE at the heart of the Sun were to go out, it would be 10 million years before the effects were felt on Earth. That is how long it takes for heat and light radiation to battle its way up through the dense interior of the Sun to its surface.

Once at the surface though, it takes only eight minutes for the Sun's heat and light waves to travel to the Earth.

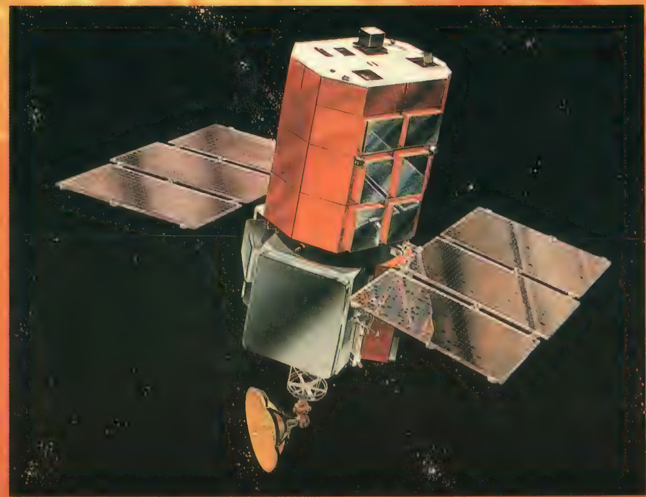
The heart of the Sun is very hot and very dense. The temperature is some 15 million degrees Celsius and over 160 tonnes of matter are jammed into every cubic metre. This matter consists mostly of hydrogen, but not hydrogen as it exists on Earth.

Crushed atoms

Normally, matter exists in the form of atoms, each of which has a tiny core, or nucleus, around which electrons orbit. But at the pressures and temperatures prevailing in the Sun, atoms are crushed together until their nuclei and electrons move independently.

The hydrogen nuclei constantly collide and fuse, eventually forming

__The Sun__ is the force behind the solar system. Satellite Solar Max (right) was launched by the Space Shuttle to study its curious 22-year cycle of activity.



NASA/SPL

Huge prominences *of glowing red hydrogen shoot out into Space from the fiery surface of the Sun. These can only be seen during a solar eclipse when the main body of the Sun is obscured by the Moon.*

ZEFA

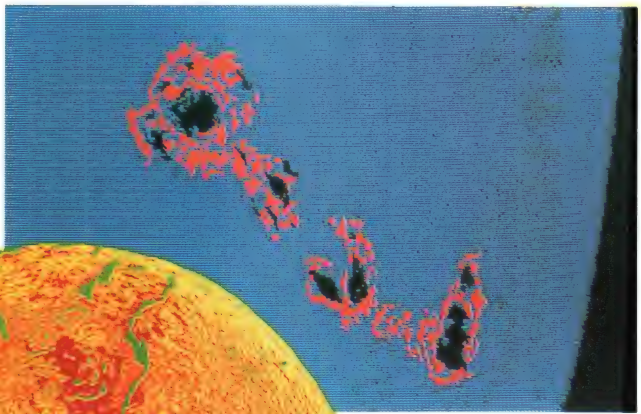
more massive nuclei of helium. This is essentially the same process as the one that powers the hydrogen bomb.

When the four hydrogen nuclei get together to form helium, they lose a tiny bit of their mass, which is given off as energy. So the Sun is constantly losing mass – in fact, around four million tonnes of the Sun's mass vanishes every second.

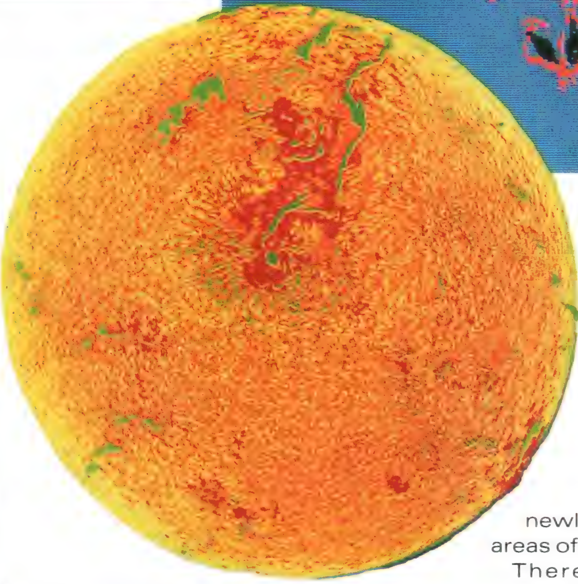
The energy generated radiates in the form of light, X-rays and radio waves, bouncing off the densely packed nuclei and zig-zagging back and forth. That is why it takes so long to emerge. About four-fifths of the way out, the process of convection takes over. Heat is carried outwards by hot gas rising to the surface.

At a temperature of 6,000°C, the surface of the Sun is a brilliant sight (though you should never look at it directly). But when it is examined minutely with astronomer's instruments, it is mottled, or patchy, with ever-changing bright areas of hot, newly risen gas among darker areas of cooler, sinking gas.

There are usually large sunspots to be seen that appear slightly dark compared with their dazzling surroundings. Sunspots appear where magnetic fields trapped inside the Sun burst through the surface. These slow down the convection of gases, allowing patches to cool.



Nigel W Scott/Science Photo Library



Science Photo Library

False colour image *showing sunspots as green dots. Active regions are red. The green lines are filaments – near the Sun's edge they would show as prominences. Sunspots (above) just before the height of the 11-year cycle.*

LOOKING AT THE SUN

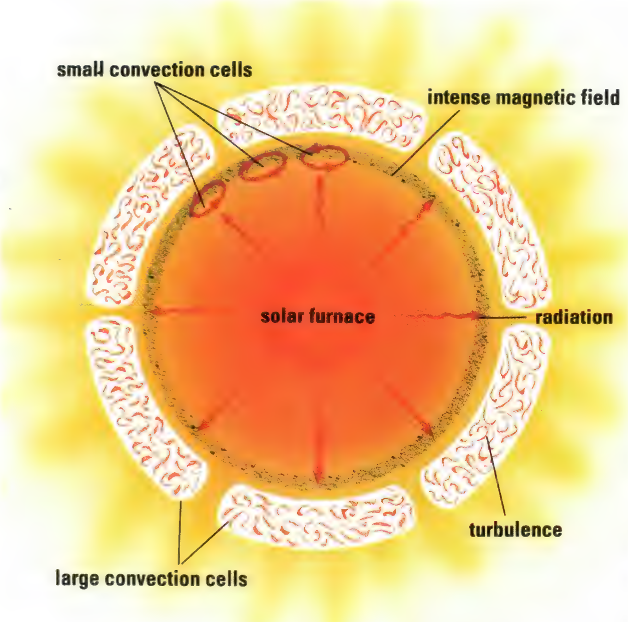
Using smoked glass or dark glasses is *not* a safe way to look at the Sun, with or without binoculars or a telescope. The safe way is to project an image of the Sun on to a piece of white card. Mount the card behind the telescope or one of the eyepieces of a pair of binoculars as shown.

Another piece of card around the barrel of the instrument will shade the card on which the image is projected. If you do not have binoculars or a telescope, a small hole in the upper card will form a 'pinhole image' of the Sun.

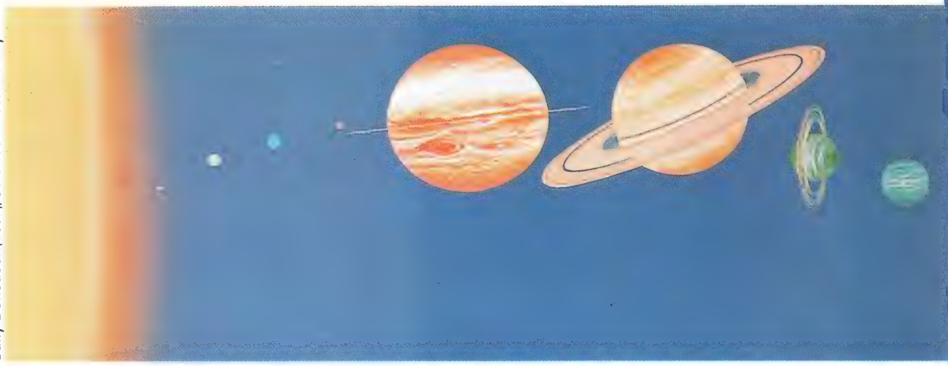
The image produced is of low quality, but it will show clouds passing over the Sun, and even large sunspots if any are present at the time. Solar prominences and the corona cannot be seen except with specialized equipment or during total eclipses of the Sun, which are very rare.

David Parker/Science Photo Library

In the dense core *of the Sun, energy radiates outwards as light, X-rays and radio waves. In the outer fifth though, the plasma is less compact, allowing huge zones of convection to form where cells of swirling hydrogen carry the energy to the surface.*



Mark Franklin



Sally Bensusen(1987)/Science Photo Library

***The Sun** dwarfs the planets of the solar system. Shown approximately to scale here they are (from left to right): Mercury, Venus, Earth, Jupiter, Saturn, Uranus, Neptune and Pluto.*

Magnetic fields outside the surface are often traced out by great arching streams of glowing red hydrogen. Called prominences, they dwarf the Earth, sometimes extending to half the width of the Sun.

Extending far beyond the Sun is a very thin but extremely hot solar 'atmosphere'. This is called the corona and has a temperature of two million degrees Celsius. Particles from the corona escape, causing the solar wind. Some of these are captured by the Earth's magnetic field. As they spiral towards the Earth's magnetic poles, they hit the atmosphere causing the northern and southern lights.

Solar cycles

Solar activity goes through a regular cycle. The number of sunspots grows over a period of about four years, then decreases for about seven years. When the number of spots is at a maximum there are more prominences and flares – or explosions on the surface.

ZEFA

***France's solar furnace** in the Pyrenees collects the energy of the Sun with a series of huge mirrors and focuses it to a single point, just like a magnifying glass. This produces the temperatures you would find inside a conventional furnace.*

The magnetic fields associated with the spots change their direction between one 11-year cycle and the next. So the Sun's cycle is really 22 years long – the time between sunspot maximums of the same magnetic direction.

Waves of suicide, wars and stock market crashes have all been linked to the solar cycle but no convincing explanation of why this should be has been advanced. However, it has been established that sunspots affect the weather. The rings in a tree trunk show the annual growth of that tree. A thick ring corresponds to a wet year when the tree grew more. Eleven year cycles can be found in these rings.

Some 680-million-year-old rocks from Australia were formed from mud and silt deposited in shallow waters. Very thin reddish bands in the layers are thicker where the mud was deposited fastest – in rainy years when rivers flowed fastest. The bands show an 11-year variation. And temperature records between 1855 and 1985 show a 22-year cycle that keeps step with that of the Sun's activity.

The Sun is the source of all life on Earth. The energy of sunlight is used by the leaves of plants to build up foodstuffs for themselves and by animals when they, in turn, eat the plants. The Sun also maintains the comfortable temperature range in which life can survive.

But the Sun also poses hazards to human beings. Invisible infrared and ultraviolet waves from the Sun pass through the atmosphere. Infrared waves are felt as heat. Ultraviolet waves can cause the skin to 'burn'.

The ozone layer

Fortunately, most ultraviolet radiation is blocked by the ozone layer 20-35 km up in the atmosphere. Ozone is a gas whose molecules consist of three atoms of oxygen – ordinary oxygen molecules contain only two. When ultraviolet radiation from the Sun passes through the atmosphere, the shorter-wavelength part of it causes oxygen molecules to react to form ozone molecules. Much of the ultraviolet is absorbed in the process. At the same time, ozone molecules are continually broken down into oxygen again, thanks to longer-wavelength ultraviolet radiation, which is also absorbed in the process.

Damaging chemicals

In 1985, scientists found that the ozone layer was thinning out over Antarctica every spring. This thinning, which intensified every year between 1985 and 1994, has also been observed to a lesser extent in the Arctic. It is blamed on chemicals called chlorofluorocarbons, or CFCs, which are used in such things as aerosol spray cans and refrigerators. In the atmosphere, the CFCs break down to produce chlorine, which damages the ozone layer by breaking down ozone molecules. CFCs are being rapidly phased out and substitutes are being sought for use in such products.

Just amazing!

THE LONGEST DAY

WHEN SOLAR FLARES BOMBARD THE EARTH WITH PARTICLES, THE ATMOSPHERE SWELLS SLIGHTLY, SLOWS THE EARTH'S ROTATION AND MAKES THE DAY MEASURABLY LONGER.

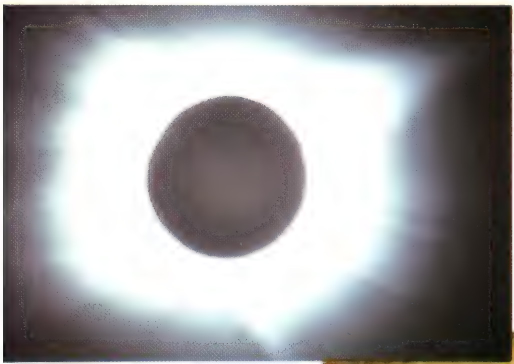
Paul Raymonde

The Sun was born five billion years ago from a swirling cloud of gas and dust, like those that can still be seen throughout the Galaxy. The cloud slowly collapsed under its own gravity. As it did so, energy was released that heated the core of the cloud. For perhaps 50 million years the Sun continued like this as a protostar – its heat and light gradually blowing away the surrounding outer layers of the cloud which formed the planets. Then, when the temperature at the centre reached about 10 million degrees Celsius, nuclear reactions were triggered and the Sun became a true star.

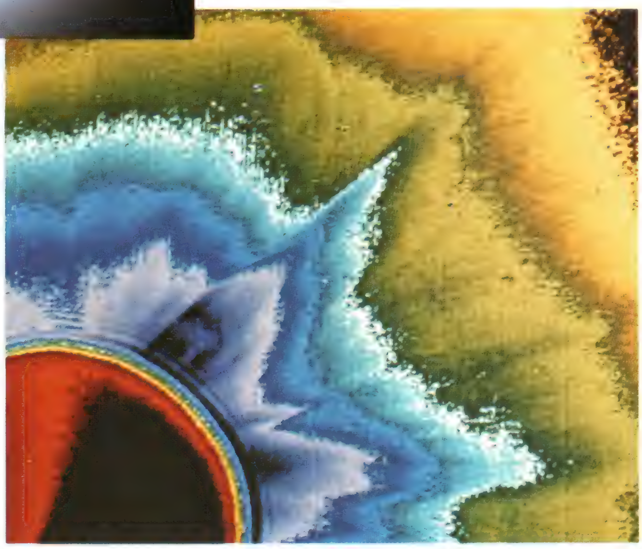
The Sun is an average star, one of a hundred billion in the Galaxy. It has about another five billion years to go before it starts to run out of the hydrogen that fuels its central core. It will then start to consume the helium that will have accumulated, forming heavier nuclei of such elements as carbon and oxygen. As the helium runs out, it will start to use up these heavier nuclei in turn. As it does so, it will cool. The Sun will swell to become a type of star called a red giant, which will be about 10 per cent brighter than it is now. In 1994, a group of American astronomers estimated that in 1.1 billion years' time the Earth will be scorched, losing its atmosphere and oceans. Life will cease to exist.

PROFILE — THE SUN

Average distance from Earth	149.6 million km
Diameter at equator	1,392,000 km
Time of revolution	25.4 days
Mass	1,989 trillion trillion tonnes (332,800 x mass of Earth)
Average density	1.41 x density of water (Earth's density is 5.5 x density of water)
Density at centre	160 x density of water
Surface gravity	27.9 x Earth's surface gravity
Escape velocity	617.7 km/s
Surface temperature	6,000°C
Core temperature	15 million degrees C



Dr Fred Espenak/Science Photo Library



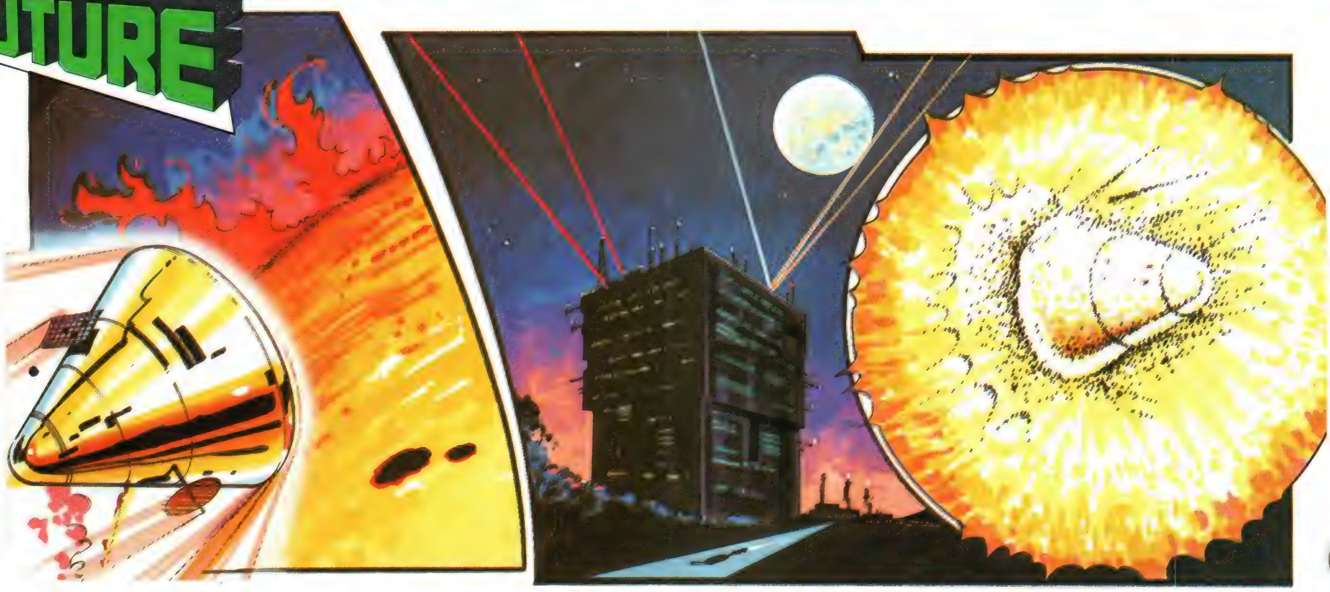
NASA/Science Photo Library

***The solar corona** pictured by a coronagraph on the Solar Max satellite. The colours denote the intensity of light – brighter areas are blue. Normally it is impossible to see the thinner, fainter corona unless the bright body of the Sun is blocked out by a coronagraph or by the Moon during an eclipse of the Sun (above).*

White dwarf

After some billions of years as a red giant, the Sun will become unstable, occasionally being rent by explosions and throwing off shells of gas – probably destroying what is left of the Earth. Finally, it will shrink to become a dim white dwarf star, the size of the Earth, and fade away into obscurity.

INTO THE FUTURE — SUN PROBE



▲ *A Space probe could one day be sent right into the Sun itself. It would have to have a mirror-like surface to reflect the Sun's heat.*

▲ *Data would have to be sent back to Earth by laser beam, since interference near the Sun would be too great to pick up a radio signal.*

▲ *The probe would finally be evaporated by the great heat of the Sun – but only after it had passed through the outer layers that give off light.*

Joe Lawrence

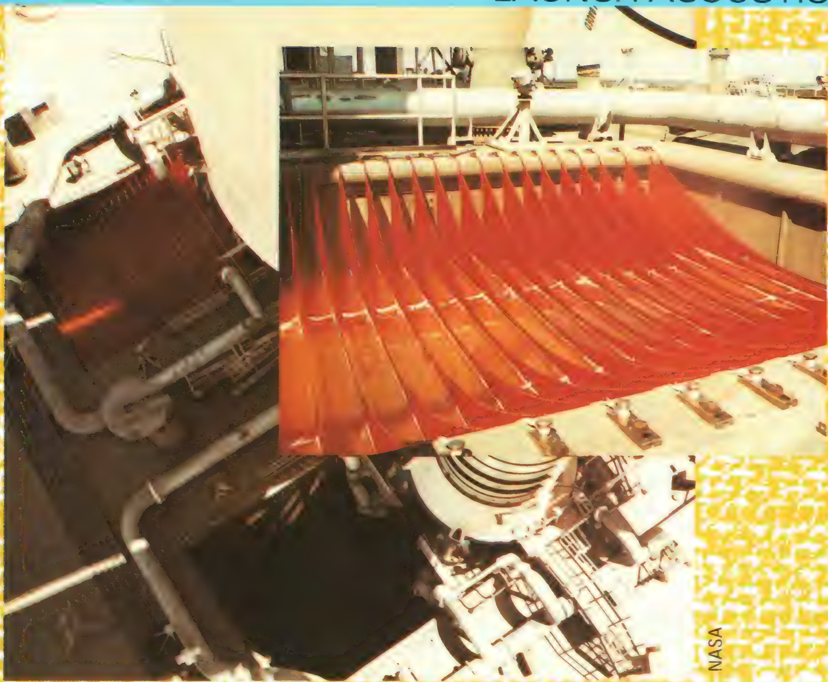
BLAST OFF

HOLDING A ROCKET STEADY before take-off, the launching gantry serves as the umbilical for both the astronauts inside and the technicians outside. The largest and most complex launch pads in use are those that service the American Space Shuttle

After returning to Earth, a US Shuttle is prepared for its next mission inside the 160-metre-high Vertical Assembly Building at Kennedy Space Center in Florida. Here, the orbiter is mated to its external fuel tank and twin solid-fuel rocket boosters, then placed on a Mobile Launcher Platform (MLP). This massive steel structure, 8 metres high, 49 metres long, and 41 metres wide,

NASA/Science Photo Library

The Fixed Service Structure provides access to the Space Shuttle. The Orbiter access arm and the arm that holds the 'beanie cap' are retracted on launch. NASA



NASA

NASA

During launch, the tremendous noise from the Shuttle's engines could reflect off the pad and damage the Orbiter. The high level of low-frequency noise could also damage the payload as this is carried much closer to the pad than in other rockets. To prevent this happening an acoustic suppression system is used whereby huge amounts of water are sprayed over the launch area by six conical steel castings. These castings are known as 'rainbirds' and each one is approximately twice the height of an average person.

The water is pumped from a 1.35 million-litre tank, 88 metres off the ground, at a rate of 67,600 litres per second just before the main engines are started. The resulting cushion of water absorbs much of the sound and sound-generated vibration and can also act as a fire extinguisher in the event of an accident. During test firings of the main engines or following a launch abort, the deluge also cools the back end of the Shuttle.

weighing 3,733 tonnes, serves as a portable launch pad for the Shuttle. The MLP is carried to one of two nearby launch sites at Cape Canaveral on the back of a giant crawler-transporter known as the 'mighty tortoise'.

Each Shuttle launch pad is roughly equivalent to the size of three football fields. The most prominent features of each pad are the Fixed Service Structure (FSS) and the Rotating Service Structure (RSS).

The FSS is a huge, square tower, 75 metres tall, with 12 work levels at six-metre intervals. Swing arms provide access for astronauts, ground crews, and equipment.

Access arms

One specialized swing arm, called the Orbiter Access Arm, is connected to the orbiter's crew hatch. It has a special room on the end known as the 'white room' because of its germ-free atmosphere. The arm can swing from a fully extended to a fully retracted position in 30 seconds. It remains attached to the orbiter until seven minutes before launch, and can be used as an emergency exit by the crew.

Another important arm has a small round dome on the end, known as a 'beanie cap'. Measuring four metres across, the beanie cap clamps on top of the external fuel tank and warms it with heated nitrogen. This prevents the liquid oxygen vent system at the top of the tank from developing an ice coating that could damage the spacecraft during take-off.

The Shuttle is secured to the MLP by eight attach posts, four on each solid rocket booster. Upon launch, explosive nuts fire, releasing huge linking studs between the boosters and the attach posts on the MLP.

The other main component of the launch complex, the Rotating Service Structure, is hinged to one corner of the Fixed Service Structure and rotates on a special track embedded in the pad. It is 31 metres long, 15 metres wide, and 39 metres high.

The RSS also has a number of work levels. Its main purpose is to provide a germ-free environment for transferring satellites and other payloads from their protective canisters to the orbiter's cargo bay.

***The Ariane 401 rocket** with its two liquid propellant boosters at the European Space Agency's launch base. The rocket stands 60 metres tall and can lift payloads of 1,900-4,800 kg.*

David Parker, ESA/Science Photo Library

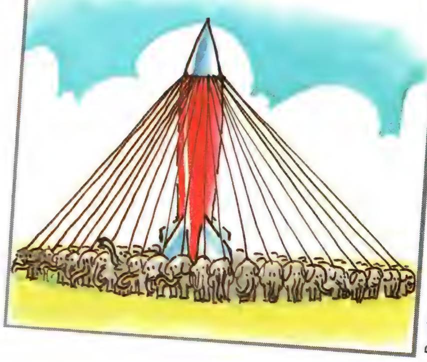
Deflector system

The MLP fits over a thick concrete slab in the centre of the launch pad called the hardstand. The hardstand's most important feature is the flame deflector system – a trench, 149 metres long, 17 metres wide, and 12 metres deep. At the bottom of the trench is a 450-tonne block of steel, coated with materials that flake off at high temperature, in the shape of an upside-down 'V' with curved sides. At blast-off, the exhaust from the Shuttle's main engines and boosters pours down through three openings in the MLP and is guided away horizontally by the deflector system.

Just amazing!

TALL AND MIGHTY

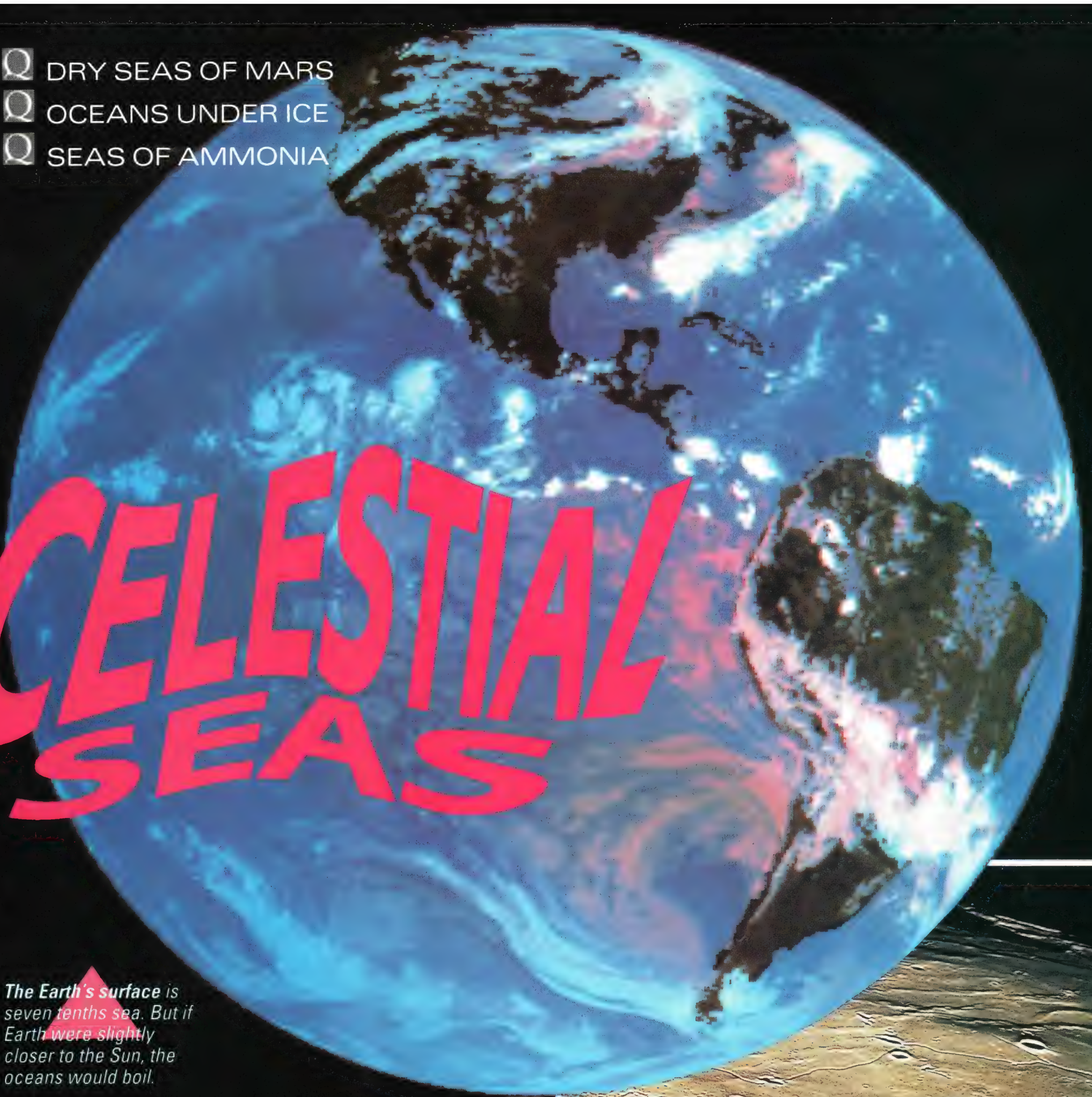
THE TALLEST LAUNCH TOWER EVERY BUILT – 136 METRES HIGH – WEIGHED 4,808 TONNES – EQUIVALENT TO THE WEIGHT OF 960 ELEPHANTS.



Paul Raymonde

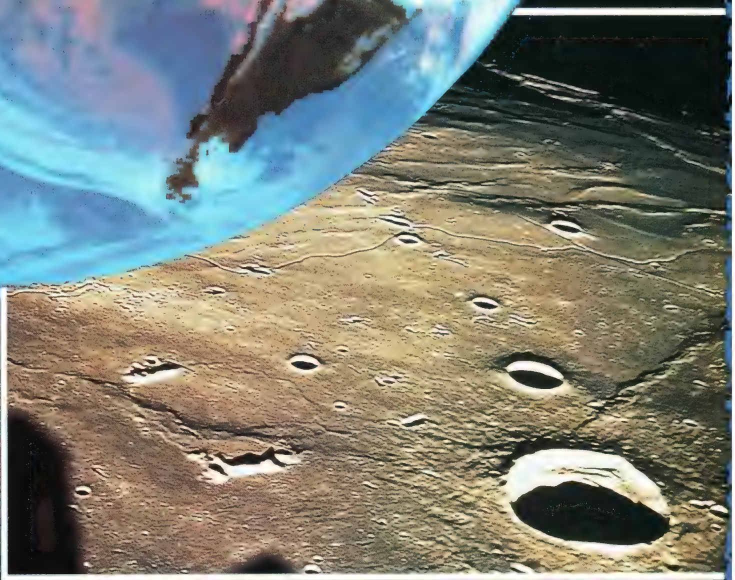
- DRY SEAS OF MARS
- OCEANS UNDER ICE
- SEAS OF AMMONIA

CELESTIAL SEAS



The Earth's surface *is seven tenths sea. But if Earth were slightly closer to the Sun, the oceans would boil.*

Hasler & Pierce/NASA, GSFC/SPL



The first Moon landing *was in the Sea of Tranquillity. This is not a sea of water, but a sea of rock. There may be water on the Moon, locked up in the rocks or frozen near the poles.*

NASA/Science Photo Library

SEEN FROM OUTER SPACE, the Earth's most notable feature is its colour – blue, the colour of the oceans. But the Earth is not the only planet in the Solar System to have seas.

Venus has clouds – a haze of ice crystals. But the atmosphere contains less than half a per cent water vapour and the rocky surface is much too hot – at 450° C – to sustain an ocean.

There are clouds on Mars too, clouds of water vapour much like those on Earth. Mars also has polar ice caps that advance and recede with the seasons. Under the surface too there may be ice in the form of permafrost, like the frozen subsoil found in the polar regions of Earth.

Martian canyons

On the surface of Mars there is evidence of erosion in the shape of enormous canyons, apparently cut by flowing water. Although water can only exist there now as ice or water vapour, in the past the Martian atmosphere may have been thicker, dense enough to allow liquid water to flow across the face of the planet cutting out these huge channels.

Thousands of kilometres below the swirling clouds of Jupiter, probably lies the surface of a dark, thick sea of liquid hydrogen, lit only by lightning bolts. This huge body of liquid hydrogen may extend tens of thousands of kilometres down until it meets a small, hard core at the planet's centre.

One of the moons of Jupiter, Europa, has a smooth surface covered with ice 75 to 100 km thick. Between the layer of ice and Europa's rocky surface there may well be seas of liquid water. Although Europa's surface is far colder than the chilliest Antarctic night, its interior is probably quite warm. Heat produced by the decay of radioactive elements deep inside the moon may have melted the ice. There was certainly water on Europa at one time. Huge fissures can be observed in the surface where water has penetrated cracks in the rock and frozen.

Viking halls

Another of Jupiter's icy moons, Callisto, may have liquid water beneath the surface as its density is only 1.8 grams per cubic centimetre, less than twice that of water. But its surface is frozen with a daytime

temperature of −120° C, dropping to −190° C at night.

Its surface does have two large formations that look like the circles of ripples formed when you drop a pebble in water. Like the craters of our Moon, they seem to have been formed by impact. Perhaps the impact there was so severe that the icy surface melted for a moment, then froze again leaving the ripply pattern in the short-lived sea frozen there forever.

The two circles are known as Asgard and Valhalla. Asgard is the mythical home of the Norse gods and Valhalla is the great hall where Odin feasted with dead Viking heroes.

Julian Baum/Science Photo Library

***Uranus** seen from its moon Miranda, as depicted by an artist. The surface of Miranda shows signs of erosion, probably by flowing glaciers.*

***Jupiter's moon** Io may have seas under its frozen surface. Saturn's cloud-shrouded moon Titan (below) may have seas of liquid methane.*

PLANETSCAPING

Planets on which no liquid water exists today could be engineered in the future to have rivers, lakes and seas. This would be done by a technique called terraforming. In the case of Mars, for instance, dark rock could be mined from the two small Martian moons, Phobos and Deimos. Scattered over the poles of Mars, this material would absorb more of the Sun's heat and so cause the polar caps to melt. The melt water could be used to grow plants and, by evaporation, to thicken the atmosphere. The greenhouse effect of the increased water vapour in the atmosphere would warm Mars further, perhaps unlocking huge reserves of water that may currently lie frozen deep underground.

There are also indications that the icy surface of Saturn's brightest moon Enceladus thaws occasionally. In certain areas there are no craters at all, as if ice has melted and refrozen into a smooth surface.

Another of Saturn's moons, Titan, is shrouded by clouds of natural gas. Scientist believe that drizzle and rain from these clouds would cause a global ocean 1 km deep. However, radar probes indicate that there are areas of dry land as well as huge seas of liquid methane.

Glacier action

Two of Uranus's moons – Miranda and Ariel – have traces of erosion, but probably due to ice warm enough to flow like a glacier, rather than water.

Before the American Space probe Voyager reached Neptune, it was thought that one of its moons, Triton, had seas of liquid nitrogen on its surface. But at −236°C, it was too cold even for that.

Elsewhere in Space, where conditions are right, there may be planets with seas of ammonia. These would seem bizarre by Earth standards. The temperature of an ammonia sea, at normal atmospheric pressure, could be between −33.4° C and −77.7° C. Stranger still, any icebergs in such a sea would sink to the bottom. While ice is lighter than water and floats, frozen ammonia is heavier than liquid ammonia and so sinks down.

Seas of poison

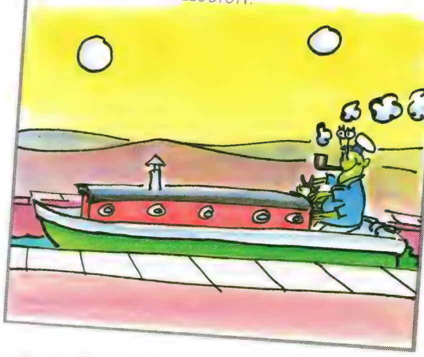
On other worlds, oceans might form from sulphur dioxide. Normally, on Earth, this is a poisonous gas. But between −10°C and −72.7°C it exists as a liquid. Nitrogen, methane and other gases could also form sub-zero seas or lakes on worlds orbiting other stars.

So it turns out that the Solar System is not a good place for oceans. Water only occurs in liquid form in a very narrow range of temperatures – just 100°, between 0°C and 100° C at Earth's atmospheric pressure. Most planets and moons have an atmosphere so thin, or non-existent, that water can only exist in the form of ice or water vapour and no seas, as we know them, could form.

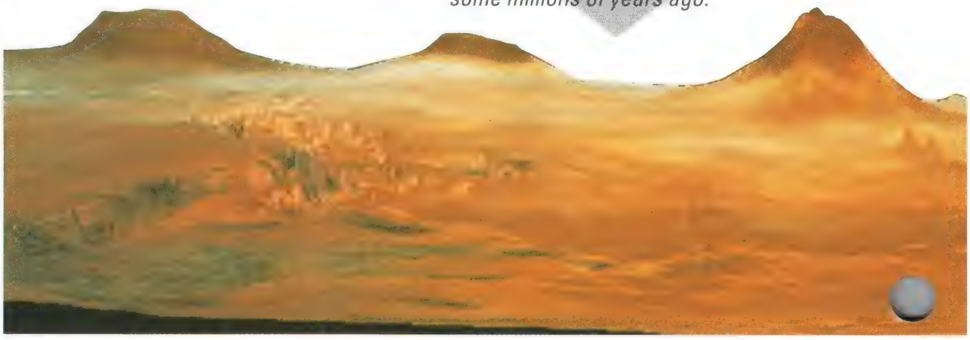
Just amazing!

MARTIAN MASTERBUILDERS

A CENTURY AGO, SOME OBSERVERS SAW FINE LINES ON MARS, WHICH THEY THOUGHT WERE CANALS DUG BY MARTIANS. BUT THEY TURNED OUT TO BE AN OPTICAL ILLUSION.



Paul Raymonde



***The Valles Marineris** – one of the Martian canyons. These show signs of erosion by water some millions of years ago.*

US Geological Survey/Science Photo Library

NASA/Science Photo Library

JPL/NASA

OUT OF THIS WORLD

AS YOU READ THIS, FOUR robot spacecraft are heading towards the stars, carrying with them pictures and sounds of the planet Earth. If intelligent aliens ever find them, they will be given an insight about human beings and be able to detect our whereabouts.

Two of these interstellar probes, Pioneers 10 and 11, became the first spacecraft to fly by the giant outer planets Jupiter and Saturn. Launched in 1971, Pioneer 10 made its rendezvous with Jupiter in December 1972 before heading on a path that carried it out of the Solar System. Its sister craft, Pioneer 11, travelling one year behind, was redirected by Jupiter's gravity pull to an encounter with Saturn in September 1979.

Coded greetings

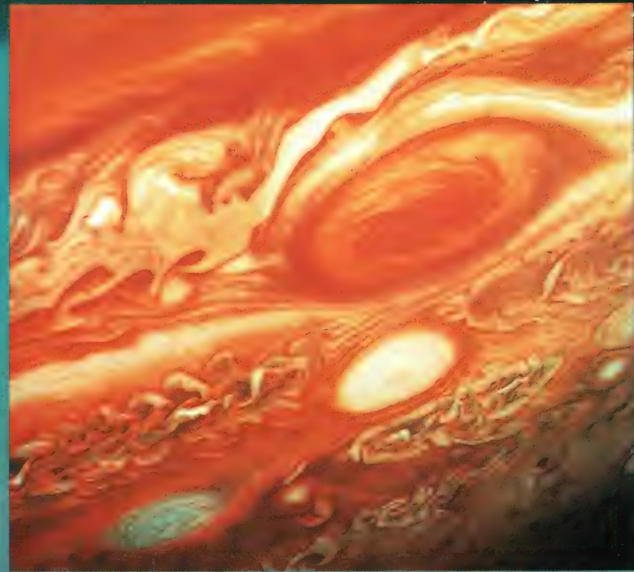
Each Pioneer carries a gold-anodized aluminium plaque, 15 cm across, fixed to one of the antenna support struts. Coded information on the plaque shows the position of the Sun in the Galaxy, together with the nine planets that orbit the Sun and an arrow to indicate that the spacecraft came from Earth.

Alongside is a drawing of a man and a woman standing in front of the probe. The man has his right hand raised in a gesture of friendship.

The twin Voyager probes, launched in 1977, have a far more

Julian Baum/Science Photo Library

***Voyager 2** is depicted during its close encounter with Uranus in 1986. The great gas giant is unique in that it tilts 98° to the plane of the Solar System.*

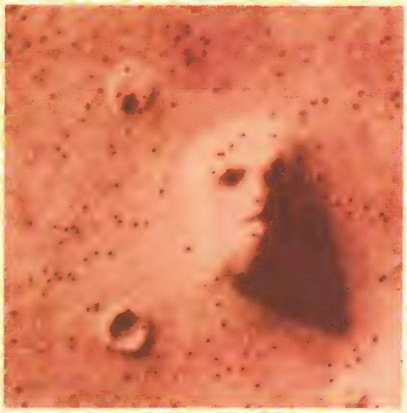


NASA/Science Photo Library

***The Great Red Spot** of Jupiter is a massive storm system that has been observed for over 200 years. This photograph, taken in 1979 by Voyager 2 from a distance of 6 million kilometres, also shows smaller cloud structures and vortices.*

THE HUMAN FACE OF THE RED PLANET

One amazing picture of the surface of Mars sent back to Earth by the Viking mission, in 1976, shows what looks like a giant human face. Measuring about three kilometres across, the face is thought by most scientists to be just a trick of the light. But in 1988, studies by an American computer programmer suggested that the object might continue to appear as a face if viewed from other directions. It seems to have a nose, two eye sockets and even a set of teeth in its mouth. Future spaceprobes to Mars will no doubt take a closer look to see if the face really is an alien art form or just an unusual natural feature.



NASA/Science Photo Library

Just amazing!

LIFE DRAWINGS

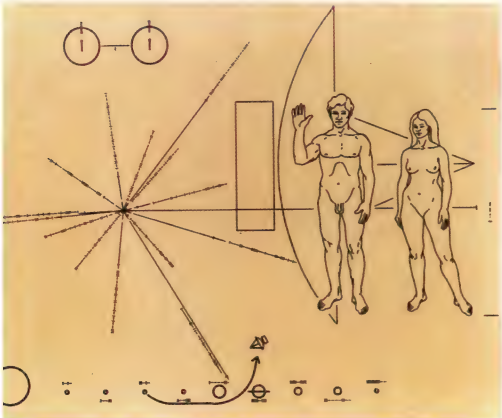
Paul Raymonde

sophisticated message aboard for any extra-terrestrials that may discover them. A phonograph has been fixed to the side of these spacecraft. This contains 90 minutes of the world's greatest music, greetings in 56 languages, and 118 pictures of the Earth and its inhabitants. A stylus is also provided together with instructions on the protective covers on how to play the record.

One of the problems faced by the creators of the Voyager record was to decide exactly what images and sounds to include. Any intelligent aliens that may exist among the stars would probably be totally unlike us and would not understand our language. So the pictures and sounds had to be selected carefully to be both clear and informative.

Among the photographs digitally encoded on the Voyager record were those of children in a school, workers in a factory, people eating a meal, an astronaut in Space, and builders putting up a house. Various animals and plants, views of the land and sea, and some of the world's most famous buildings were also included.

NASA



***The pictorial plaque** attached to the Pioneer spacecraft is the first man-made object to be sent out of our Solar System. From these messages intelligent extra-terrestrials should be able to calculate from where and when Pioneer 10 was launched, the average sizes of the humans that sent the craft and the craft's trajectory from Earth passing Mars and swinging by Jupiter.*

Light years away

The chances that either of the Voyager spacecraft will be found by extra-terrestrials is extremely small. If they were, it would be very far in the future. At their current speed it would take the Voyager craft about 100,000 years to reach even the nearest star beyond the Sun!

INTO THE FUTURE

NEW PERSPECTIVES

▲ Giant mirrors of wafer-thin aluminium foil may be sent into Earth orbit and unfolded to reflect laser light, beamed from Earth, to form spectacular shows.

▲ Intelligent aliens and colonists of other planets may have no concept of art for arts' sake, or may have developed art forms totally unlike anything on Earth.

▲ In the remote future, entire planets or star systems could be engineered into cosmic works of art – viewed from Earth by millions of people at the same time.

Joe Lawrence

SPACE JUNK

SPACE IS FULL OF RUBBISH. Far from being a vacuum, the Space near Earth is teeming with all kinds of junk – billion-year-old bits of debris left over from the formation of the planet and more recent trash left over from the Space programmes.

Since the first satellite, a Russian Sputnik, was launched in 1957, more than 16,000 man-made objects have been shot into Space. Most have fallen back to Earth and burnt up in the atmosphere. But 7,200 objects still remain in orbit, tracked by the North American anti-missile radar system. Many are rocket casings and dead satellites. Only 300 are working satellites. Such radar systems, however, can only track objects larger than 10 cm across. Scientists believe that there are more than 3.5 million pieces of debris orbiting the Earth that are too small to track.

Satellites

At the beginning of the Space programmes, hundreds of short-lived spy and weather satellites were launched. When they were no longer needed, they simply stayed in orbit, as useless pieces of junk.

Communications satellites placed in a geostationary orbit, above the Equator, orbit the Earth once a day. This orbit is crowded with more than 300 satellites – and with thousands of tiny pieces of debris released when the satellites

Collisions in Space *are an ever-present danger, when 3 million kg of man-made materials orbit the Earth. Scientists predict that in ten years time the total may be 4 million kg.*

David Weeks

separated from the rockets that launched them.

Early in their life, the satellites carry fuel and can be nudged and repositioned to avoid other satellites. When the fuel is exhausted, they can no longer be manoeuvred out of the way. Satellites in a geostationary orbit are

***Space junk in orbit** around the Earth. Over 7,000 man-made items more than 10 cm across have been identified by American radar systems.*

NASA

supposed to be 'fixed' so they do not alter their position relative to the Earth's surface, but they are affected by the solar wind and the gravitational pull of the Moon and other objects in the Solar System. Already there have been some near misses.

This junk-yard in Space is also a danger to astronauts. In June 1983, a paint fleck just 0.2 mm across struck the shuttle *Challenger*. Travelling at 13,000 km/h it pock-marked a window that cost $50,000 to replace.

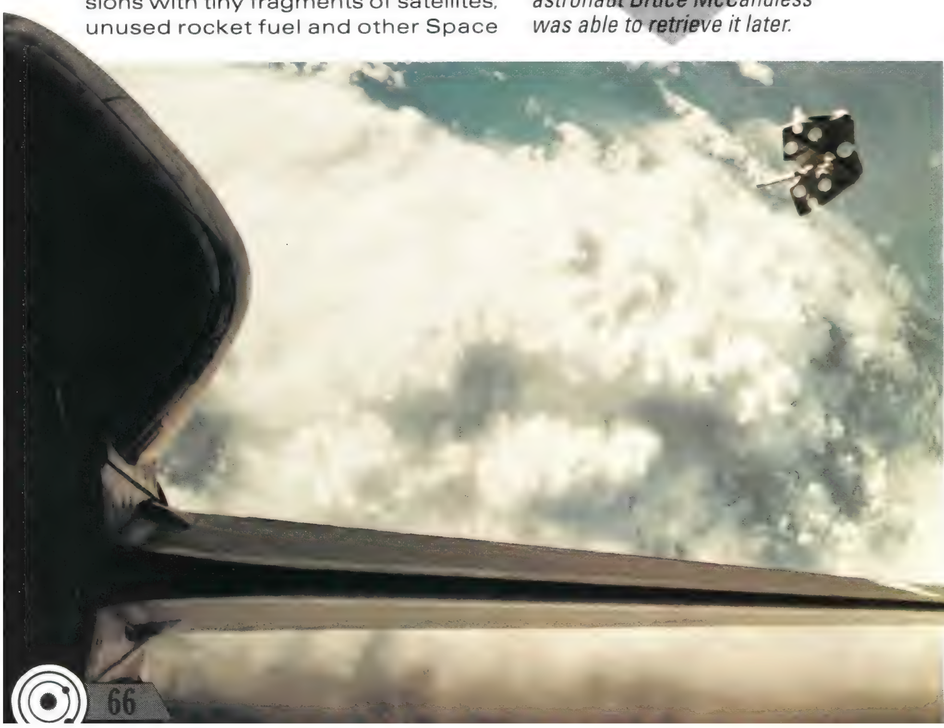
In 1984, the Solar Max satellite was disabled after thousands of collisions with tiny fragments of satellites, unused rocket fuel and other Space junk. The scientists who examined the disabled satellite found that it had also been damaged by tiny particles of frozen human urine, jettisoned into orbit on earlier manned Space flights.

The danger of collisions with debris will become even more of a problem when the Space station *Freedom* is launched sometime in the late 1990s. With a large Space station orbiting for decades, a collision would be almost inevitable.

Collision course

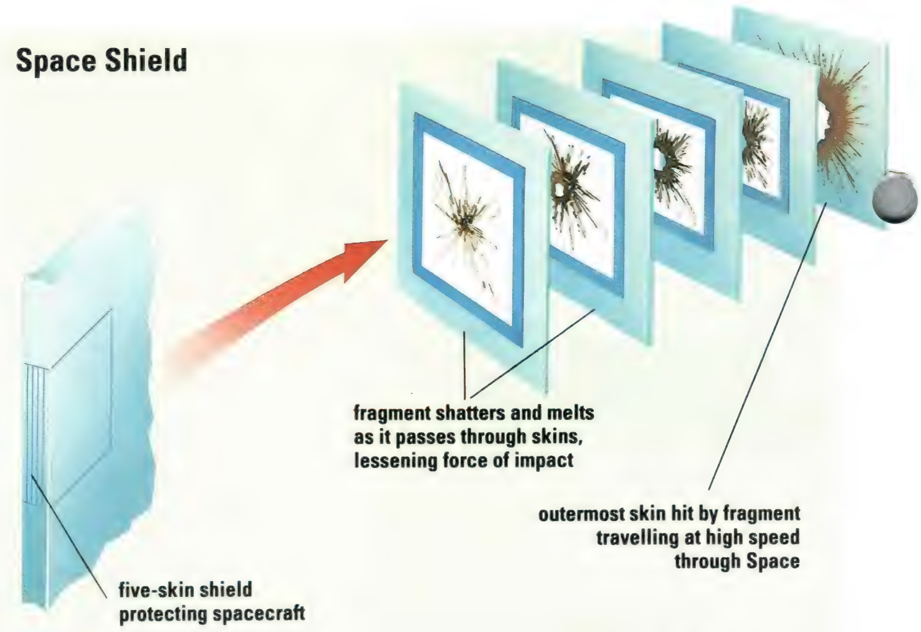
At orbital velocities, each particle of debris delivers an impact of four times its weight of TNT. A 5-cm fragment travelling at 24,000 km/h would strike the Space station with the force of a steel safe dropped from a tenth-storey window. *Freedom*'s high-pressure storage tanks, which would explode on impact, make the Space station very vulnerable.

Scientists at the American Space agency NASA have been working on the problem. One



***A foot restraint** escaped into Space during a spacewalk by two astronauts from Space Shuttle* Challenger. *Luckily, astronaut Bruce McCandless was able to retrieve it later.*

NASA/Science Photo Library



Andrew Shaw

***Five layers of ceramic fabric** form a shield that absorbs, without fragmenting, bits of orbiting junk, so debris from the impact does not float into Space.*

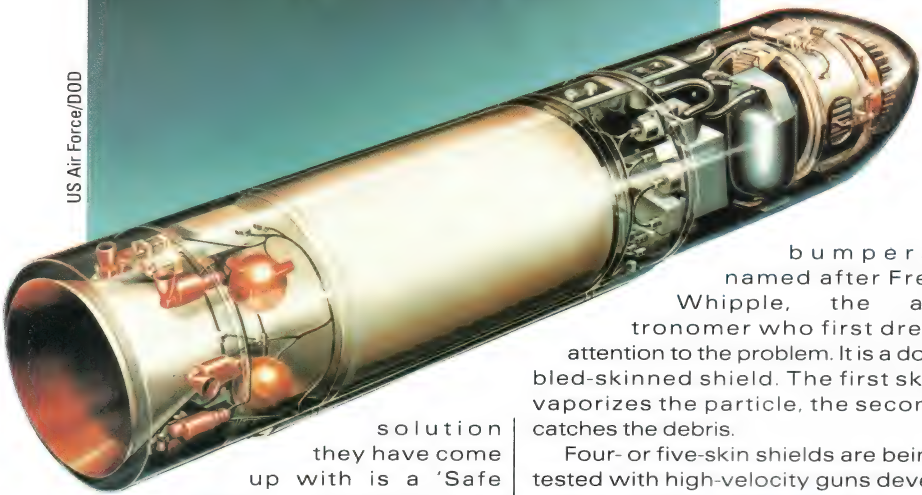
SHOOTING STARS

Telegraph Colour Library

Man-made debris falling from the skies is not the only danger. Every day, some million meteors, or 'shooting stars', hit the Earth's atmosphere. Thousands of millions of micrometeors (tiny flecks of Space dust) burn up in the outer atmosphere. Sometimes, larger objects reach the surface. Tonnes of dust from Space settles on the Earth each day. Larger meteorites hit the ground more rarely – only 14 or so large craters have been discovered on the Earth's surface. One is Meteor Crater in Arizona, USA (above), which measures 1.2 km across. An arc of islands in Hudson Bay, Canada, may be part of the rim of a crater 440 km across created by the impact of a giant asteroid. As recently as 1908 a comet hit a remote area of the USSR with the force of a nuclear explosion.

US Air Force/DOD

***A US F-15 aircraft** launches an anti-satellite missile (below) high in the atmosphere. Weapons tests account for much of the man-made debris in Space. Some 350,000 fragments were scattered through Space when, in 1984, the Solwind satellite was destroyed in just such a test.*

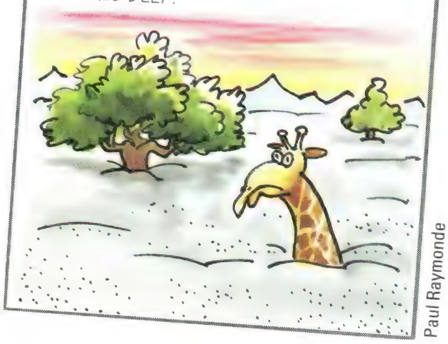


US Air Force/DOD

Just amazing!

DUSTING OVER

AN ESTIMATED 4 MILLION TONNES OF SPACE DUST SETTLES ON THE EARTH EACH YEAR. IF UNDISTURBED SINCE THE EARTH WAS CREATED, IT WOULD HAVE FORMED A LAYER OF DUST SOME 3 METRES DEEP.



Paul Raymonde

solution they have come up with is a 'Safe Haven' – a fortified module that could survive any collision. But to make it strong enough it would have to be very heavy, and it would be expensive to put into orbit. Collision-warning systems have already been put to the test on the Space Shuttle, but it would be impracticable to manoeuvre the Space station out of the way each time a piece of debris comes too close.

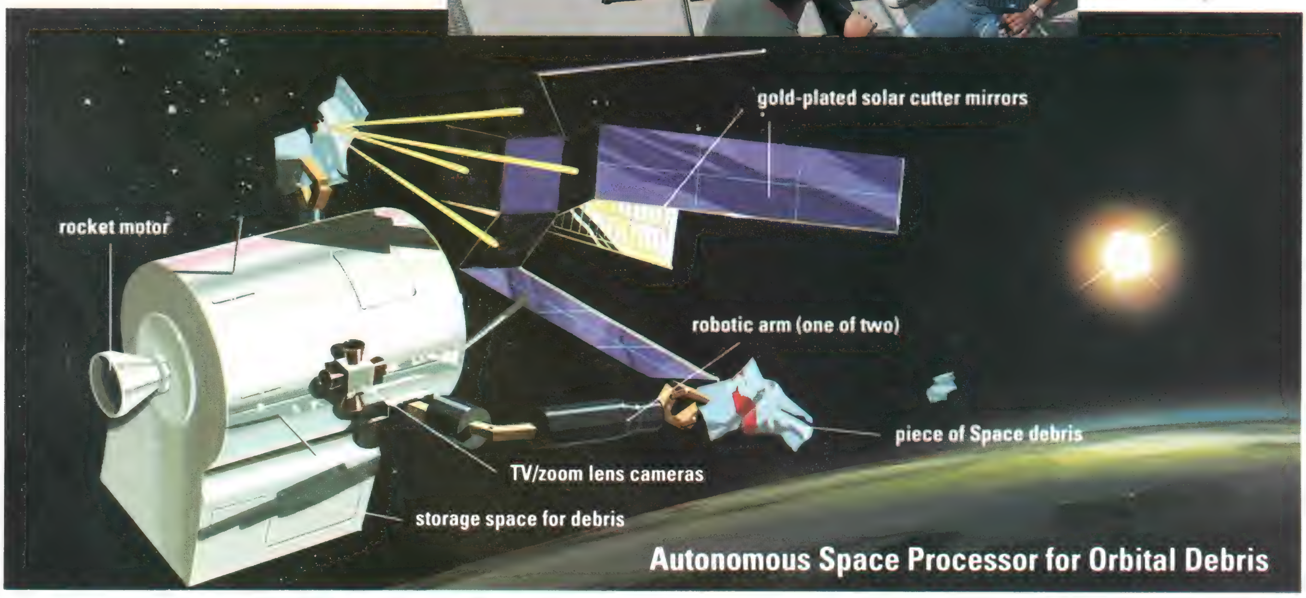
Shields are also being developed. From the beginning of Space travel, it was clear that a single skin could be easily penetrated by just one tiny meteoroid. Spacecraft have been shielded with so-called Whipple bumpers, named after Fred Whipple, the astronomer who first drew attention to the problem. It is a doubled-skinned shield. The first skin vaporizes the particle, the second catches the debris.

Four- or five-skin shields are being tested with high-velocity guns developed by NASA to simulate an orbital impact. However, each impact creates a shower of tiny droplets of molten aluminium that would make the problem of Space debris even worse. Multi-layered ceramic fabrics are being evaluated too. But none of the proposed shields could cope with an impact from fragments more than 2.5 cm long.

It is not just men and women in Space that are in peril from Space debris. At least two spacecraft have already crashed into the Earth. Skylab,

University of Arizona

***In the future,** Space debris might be disposed of by an ASPOD. Developed by American scientists (left), it grabs hold of chunks of orbiting rubbish and cuts them into smaller pieces so they can be stored until the ASPOD re-enters Earth's atmosphere and burns up.*



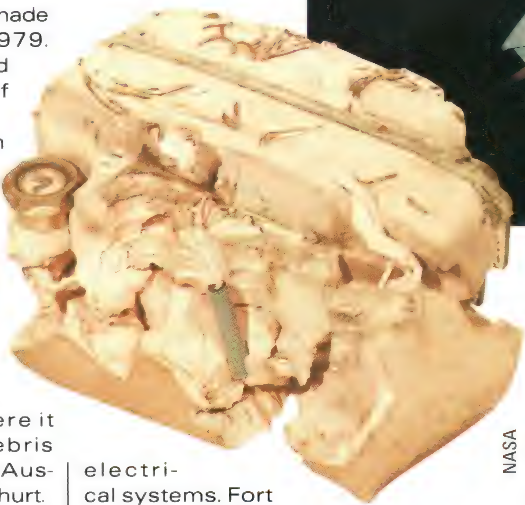
Autonomous Space Processor for Orbital Debris

Stan North

NASA

***Spacecraft shields** are tested by a hypervelocity gun. Compressed hydrogen propels a particle along the launch tube and into a shield in the target chamber.*

NASA



NASA

***Debris** showered Australia when Skylab (above) broke up. It had been planned to boost Skylab into a higher orbit with a Teleoperator Retrieval System.*

America's orbiting Space station, made an unexpected return in July 1979. Launched six years earlier, it had been occupied by teams of astronauts for a total of 170 days.

It was supposed to remain in orbit for ten years. However, unexpected solar activity increased the density of the Earth's outer atmosphere and, as a result, the spacecraft was bombarded by air molecules that slowed it down, even though it was orbiting at a height of nearly 400 km. This brought Skylab back into the Earth's atmosphere, where it began to break up, raining debris down on Earth. Fragments hit Australia but fortunately no one was hurt.

Worse, in 1978 a Soviet satellite, Cosmos 954, crashed back through the atmosphere, hitting Canada. Like many Soviet satellites, it had a nuclear generator on board to power its electrical systems. Fortunately, the uranium-235 core spread harmlessly across the Canadian tundra.

A group of engineers at the University of Arizona, USA, have designed a possible solution to the problem – an orbiting refuse collector called the 'Autonomous Space Processor for Orbital Debris'. This has radar and infra-red eyes to locate debris. Two robotic arms will grab the junk and cut it up by focusing sunlight through lenses into a point of light at a temperature of 700°C. The processor will then collect the fragments and move on. When it is full, it will plunge back to Earth and burn up in the atmosphere.

Another solution is to prevent the problem in the first place. Space agencies are now redirecting their used rocket cases upwards into Deep Space, or downward to burn up in the Earth's atmosphere. But the debris in Space already could take as long as 500 years to come down.

INTO THE FUTURE

WHEN PLANETS COLLIDE

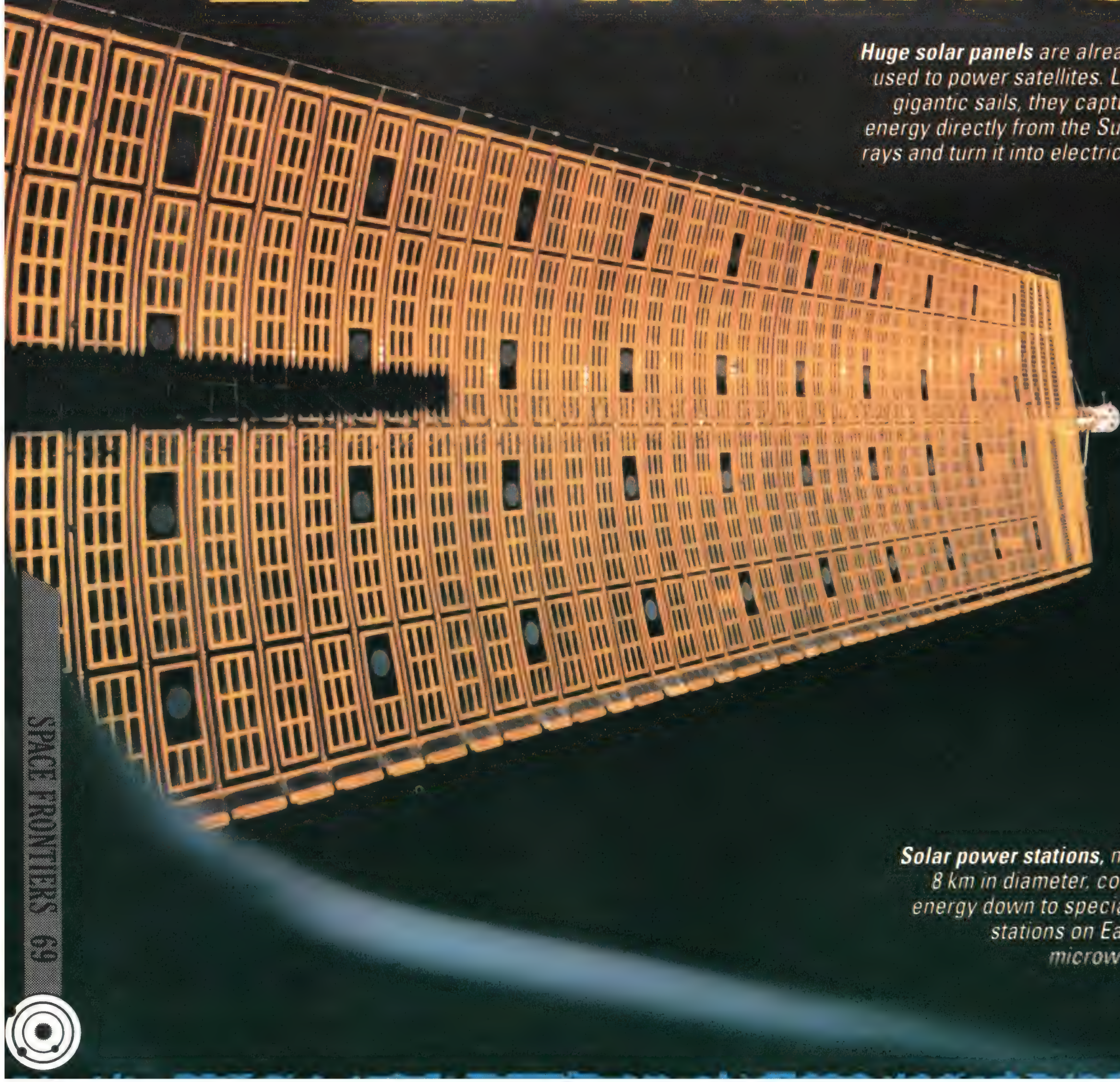
Joe Lawrence

▲ *The irregular orbit of Icarus, a mini-planet in the asteroid belt between Mars and Jupiter, crosses that of the planet Earth. A collision might be catastrophic.*

▲ *However, if Icarus were on a collision course with Earth, the asteroid, 1.4 km in diameter, could probably be deflected by hydrogen bombs mounted on rockets.*

▲ *An asteroid larger than Icarus – Eros, for example, which measures roughly 23 km across – would be much harder to divert. Impact might kill all life on Earth.*

BEAMING IT BACK



***Huge solar panels** are already used to power satellites. Like gigantic sails, they capture energy directly from the Sun's rays and turn it into electricity.*

NEXT CENTURY, HUMANKIND will be looking out into Space for energy. Not only will they be using energy from Space to power the Earth, new forms of off-Earth power will be used to propel deep Space probes.

Energy from the Sun is non-polluting, free and virtually unlimited. But solar power stations on Earth cannot produce electricity at night or on cloudy days. To avoid this problem, a huge array of solar cells, several kilometres wide, could be assembled in geosynchronous orbit, 35,900 km above the surface of the Earth.

The electricity produced by the orbiting power station would be turned into microwaves and beamed to a large receiver on the surface. These can pass right through clouds, so the beam would be able to get through day and night, whatever the weather. At the ground station, the energy in

NASA

***Solar power stations,** more than 8 km in diameter, could beam energy down to special ground stations on Earth using microwave links.*

the microwave beam would be transformed back into electricity and used to supply homes and industry. A single array, eight kilometres across, could supply the needs of a city the size of Birmingham in the UK.

Solar energy may also be used to push a new type of spacecraft to the outer planets. The pressure of light particles, or photons, coming from the Sun acts like a gentle wind. This wind could be trapped by spacecraft equipped with immense, gossamer-thin aluminium sails in the same way that a yacht uses a breeze on Earth.


David A. Hardy/SPL

Sail power *of the future – these proposed spacecraft are propelled by light emitted from the Sun. The pressure of sunlight on their thin membranes – up to a kilometre across – would power them into deep Space. The Nina (right) is bound for Mars.*

Cambridge Consultants

Interplanetary race

Such solar-powered craft could be used for slow, but sure, interplanetary travel. They would be launched by rocket into a high Earth orbit. They would then unfurl their sails and allow the Sun's radiation to push them towards Mars. They would weigh about 300 kg and have a sail the size of London's Wembley Stadium. It would be steered by flexing the sail so that different parts received more or less sunlight and should reach Mars in 200 to 300 days.

As you get further from the Sun, the strength of solar radiation falls off. However, if a powerful laser beam, stationed somewhere in ther Solar System, was trained on a photon sail, the craft could still be powered across interstellar Space.

Interstellar light sailing would involve incredibly large structures. One design, for instance, calls for a sail 100 km across but only a millionth of a centimetre thick.

Slowing down

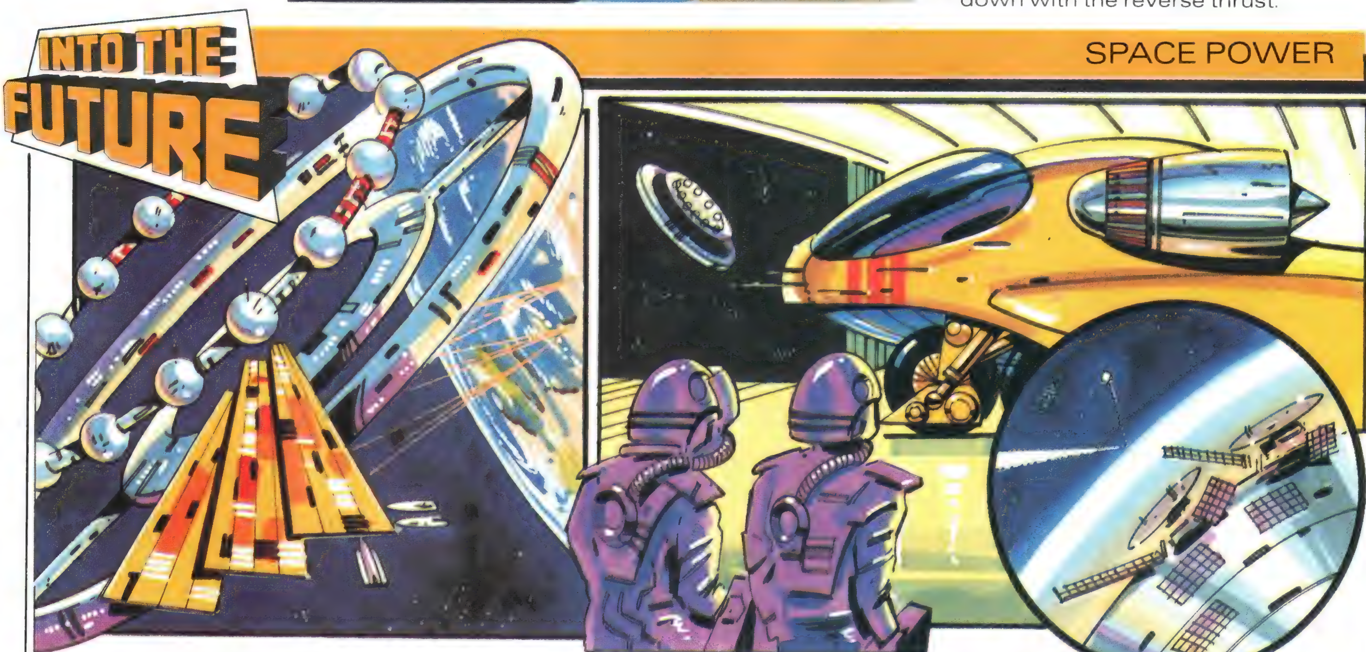
To apply the 'brakes' as the spacecraft approached its target star, the outer part of the sail would break away and move ahead of the central section. Laser light reflecting off this outer ring would then strike the central part from the opposite direction, slowing it down with the reverse thrust.

Just amazing!

LATE ARRIVAL

FOUR SPACE PROBES ARE ALREADY HEADING OUT OF THE SOLAR SYSTEM. BUT AT THE SPEED THEY ARE TRAVELLING, IT MAY TAKE THEM 100,000 YEARS TO REACH ANOTHER STAR.

Paul Raymonde



▲ *Power stations in orbit could collect solar energy and beam it back to Earth. This could provide all the energy that people might need.*

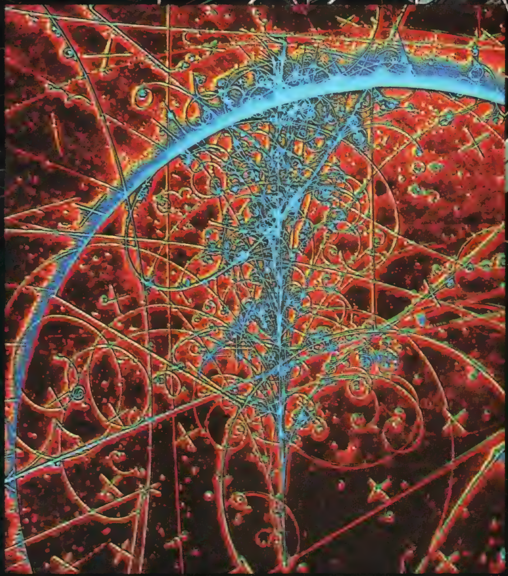
▲ *These could easily be maintained by engineers who would travel to and fro on the Space Shuttle or one of the new generation of Space planes.*

▲ *However, the stations' fragile solar panels would have to be shielded from Space debris – the tiniest fragment would tear them to shreds.*

Joe Lawrence

Q ZERO-G Q SPACE SICKNESS Q COSMIC RAYS

HIGH RISK



Patrice Loiez, CERN/SPL

***A permanently manned Space station** (artist's impression) being developed by NASA will need to address the hazards shown by experiments in Space with biological specimens. These experiments demonstrate that fast moving atomic particles (left) can severely damage the cells of living organisms.*

NASA/ SPL

IN THE FUTURE, PEOPLE MAY live in Space or go on long journeys to other planets and stars. But before that can happen some serious medical problems have to be overcome.

Not least among the hazards is radiation. When on Earth, high-energy rays from Space that are dangerous to humans are blocked by the Earth's atmosphere. These include electromagnetic waves such as X-rays and gamma rays, together with streams of fast-moving, charged particles. Above the atmosphere, however, a spacecraft is continually bombarded with these tiny bullets of energy, some of which are able to pass straight through its walls.

Charged particles moving close to the speed of light pose the most deadly threat. They can penetrate the living quarters of a spacecraft and enter an astronaut's body, destroying living cells. Exposed to sufficiently high doses, a Space traveller could develop radiation sickness or cancer.

Solar storms

Within the Solar System, by far the greatest source of energy-charged particles is the Sun. In 1956, for instance, a giant solar flare released enough radiation in half an hour to give astronauts a thousand lethal doses. Fortunately, this happened before the first manned spaceflights. Future interplanetary spacecraft will need to be equipped with solar storm shelters, shielded by fuel tanks and other radiation-absorbing hardware.

Lengthy exposure to zero-g, or weightlessness, can also be harmful to astronauts. Without having to work continually against the downward pull of gravity, a person's muscles grow weaker. This is especially worrying in the case of heart muscles, as the heart may pump blood less effectively around the body when the astronaut returns to Earth.

Just amazing!

DISINTEGRATING DINNER

IN THE SPACE SHUTTLE, BITE-SIZED CUBES OF FOOD HAVE TO BE COATED WITH A THIN LAYER OF GELATINE TO PREVENT CRUMBS FREE-FLOATING IN THE ZERO GRAVITY.

Paul Raymonde

Food onboard the Space Shuttle *can be freeze-dried, irradiated and thermostabilized. The bubble of strawberry drink shows the odd properties of liquid in microgravity conditions. Microgravity also affects the flow of blood through the body. Testing of lower body negative pressure (below) is assessing this effect, whereby blood rises to the head and chest.*

NASA/Science Photo Library

NASA

Bones are also affected by weightlessness. In orbit, the rate at which new bone material is laid down slows, which means that the skeleton becomes progressively more brittle. Living in zero-g also lowers an astronaut's immunity to disease. Though it is not clear why, a person produces fewer white blood cells – an essential part of the body's defence system – when weightless.

Weightlessness

Doing the simplest jobs in Space can be surprisingly hard. This is because our ability to do delicate tasks depends largely on being able to judge the weights of different objects. Under weightless conditions, it is much harder to know how much force to exert to achieve just the right amount of movement.

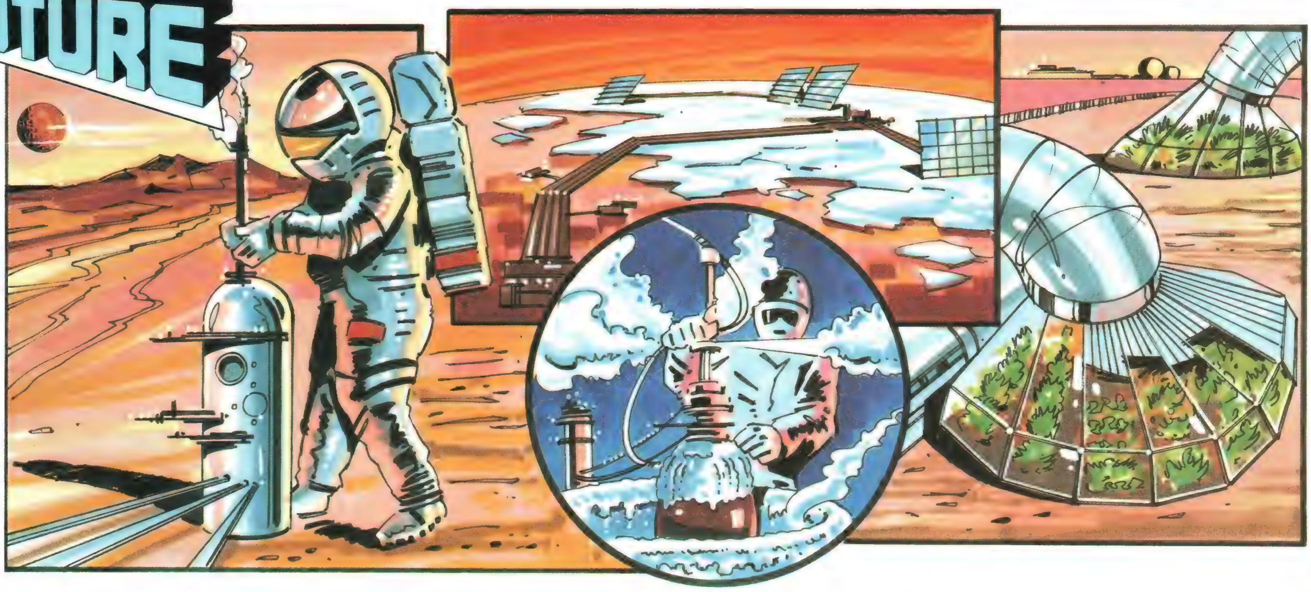
More than 40 per cent of all astronauts are sick for the first two to three days of their flight. This can mean that tasks have to be delayed or performed more slowly than usual.

The symptoms of Space sickness are like those often felt by people in a boat on rough seas – nausea, vomiting, cold sweats and drowsiness. Weightlessness, like a choppy sea, upsets a person's sense of position, movement and balance. Although an astronaut's brain and eyes may try to tell him what is up or down aboard a spacecraft, there is no gravity pull to confirm this. The resulting conflict of signals reaching the inner ear balance mechanism and being transmitted to the brain is probably what brings on the sickness.

When astronaut Edwin Aldrin saw strange flashes of light during the Apollo 11 flight to the Moon, he thought he was going mad. However, other Apollo and shuttle crews since have noticed similar flashes. Almost certainly, they were seeing cosmic rays – very high speed, charged particles from the depths of Space. Cosmic rays come to us randomly from all directions, but the Earth's atmosphere prevents them from reaching the surface. In Space, a cosmic ray can occasionally pass through an astronaut's eye causing pinpoint flashes or streaks on the retina.

INTO THE FUTURE

LIFE ON MARS

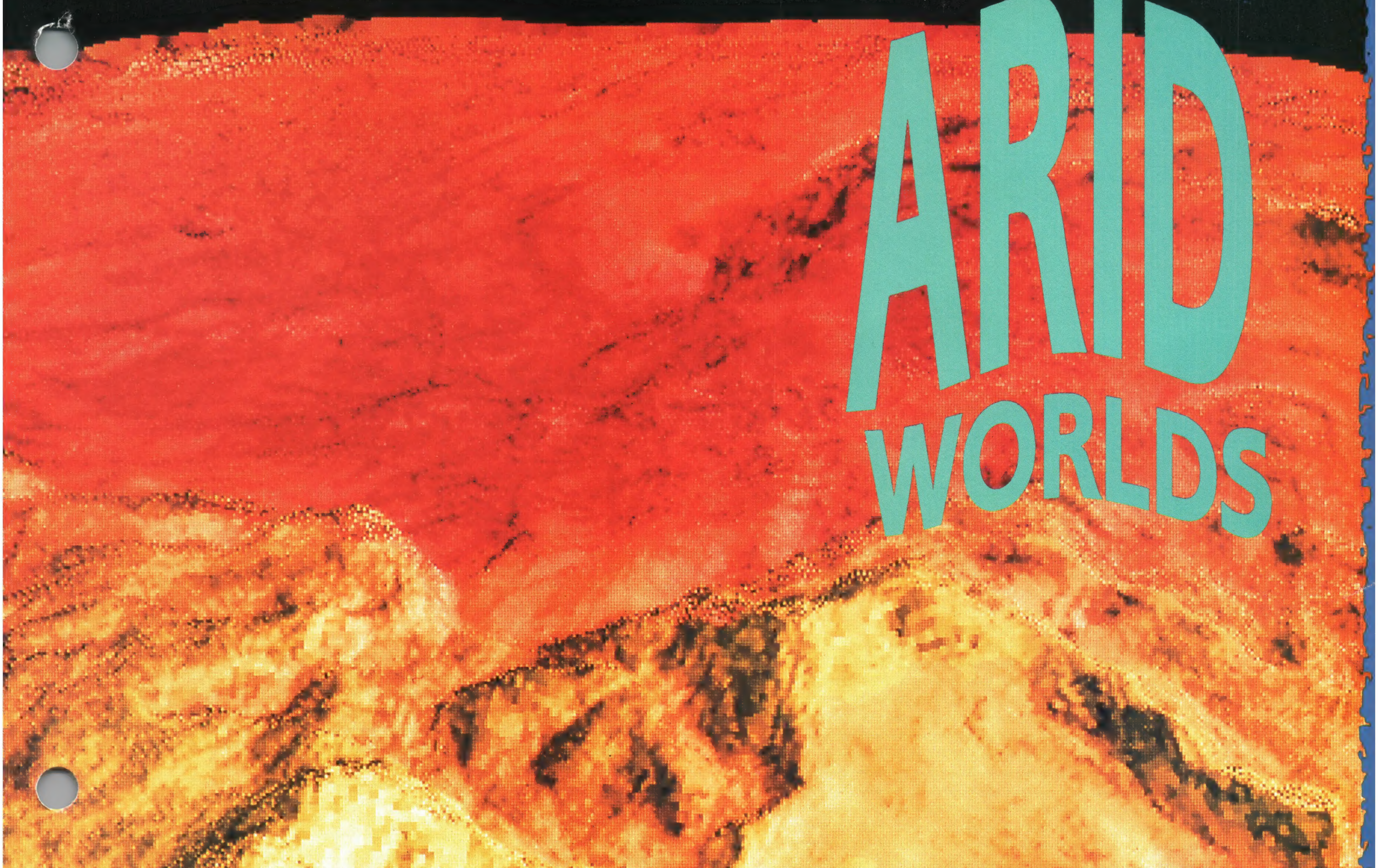


▲ Survival on Mars would not be easy. The thin atmosphere offers nothing to breathe and gives no protection from cosmic rays.

▲ Water could be melted from below the surface. Using solar power, the water could be electrolysed, providing oxygen to breathe.

▲ Although Mars contains metals that could be usefully mined, there is no nitrogen so plants could only grow in nutrients brought from Earth.

Joe Lawrence



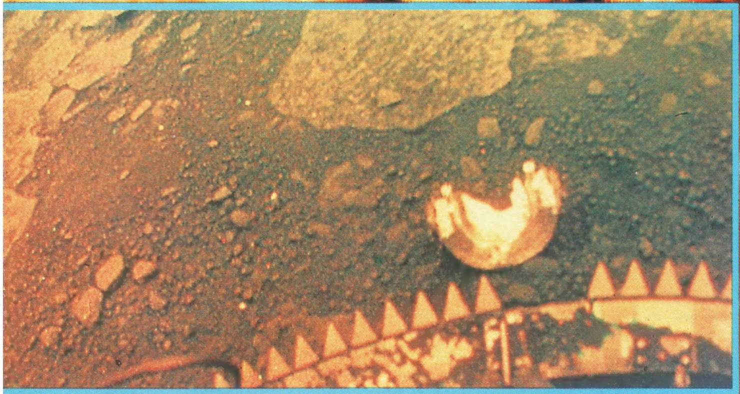
ARID WORLDS

A MANNED LANDER GENTLY sets itself down in the dust of the red planet at the start of human exploration of Mars. The scientists aboard should then be able to confirm or disprove some of the theories held about this dry, desert-like planet.

Venus, too, is dry and has rock-strewn and dusty areas. But calling the surface of any other body in the solar system desert-like is slightly misleading. The term desert only has any real meaning within the relatively narrow confines of Earth's range of habitats and climatic conditions. In fact, the worst desert on Earth is many times more hospitable to life as we know it than any surface on any of the known planets or moons. However, the two most Earth-like planets are Venus and Mars and by some definitions they are desert worlds.

Venus is covered in a thick, hot atmosphere of carbon dioxide. It has dense clouds some of which are made up of corrosive sulphuric acid, and on the dusty surface the temperature is high enough to cause lead to melt. Radar mapping has revealed active volcanoes, rift valleys and lowland vents oozing lava flows as well as areas showing craters from meteoritic impacts.

Not a very promising environment, but it certainly qualifies for desert status with its heat and the dustiness of the surface. Russian Venera Landers have revealed something about the surface itself. The atmospheric pressure is approximately 90 times that of Earth and the temperature is around 470°C. There is a gloomy orange light bathing the rock and dust-strewn surface. The atmosphere near the surface is relatively still with wind speeds of just 0.5 m/s. This means that the rocks are not weathered, but angular and new-looking.



Novosti

The USSR's Venera 13 soft-landed on the desert-like surface of Venus. Part of the craft is visible. Venera 15 and 16 and the US's Pioneer and Magellan mapped the desert surface. Pictures are combined with those from the Arecibo radio telescope in Puerto Rico (main picture).

Sand and ice

The Martian landscape is a cold windswept desert. The maximum temperature by day can reach a moderate 20°C but at night it plunges to an icy −120°C or less. The average is a chilling −23°C. The Martian deserts are either rocky, sandy, dusty or, at the poles, ice-covered.

The views from Viking 1 Lander show that the Martian surface is like rock and boulder strewn sand-covered deserts on Earth. The typical surface is wind-eroded rocks partly hidden under rock fragments, wind-blown sand and dust. There are drifts of fine powdery soil not unlike powdery Antarctic snow but, in the light of the Martian day, coloured salmon-pink by dust suspended in the air filtering the sunlight.

Sticking out of the dry, dusty surface there are giant volcanoes – Olympus Mons is 24 km high and

US Geological Survey/NASA/Science Photo Library

560 km across. And there are other signs of volcanic activity such as lava fields and rift valleys. In places, there are fields of dunes similar to those on Earth. There is terrain cratered like the surface of the Moon and, tantalizingly, what look like channels eroded by the flow of water.

The Martian atmosphere is 95 per cent carbon dioxide and 2–3 per cent nitrogen. The rest is made up of traces of water vapour, argon and oxygen (only 0.13 per cent). The atmosphere is thin, at around 7 millibars, compared with an average of just over 1,000 millibars at sea level on Earth. The lack of oxygen means that Mars has no ozone layer, so the surface is bathed in harsh ultra-violet light from the Sun, which has the unfortunate effect of sterilizing the surface and making life very unlikely.

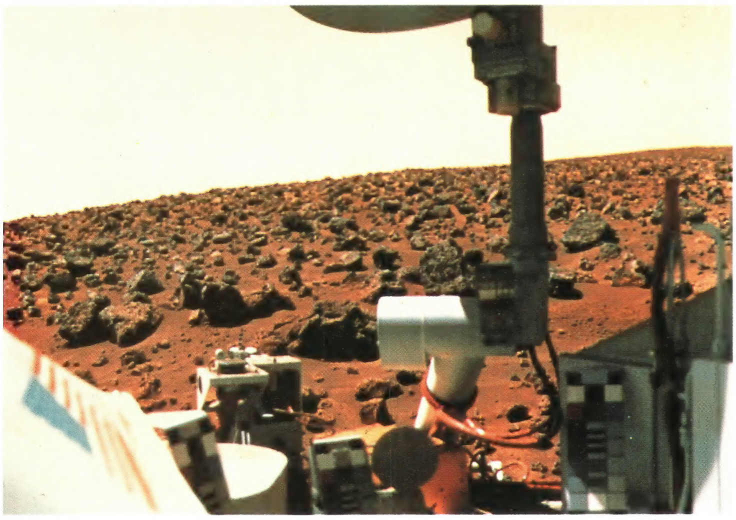
The atmosphere is, however, substantial enough to allow some solar energy to be turned into wind power. Wind speed can be quite high, with velocities of 30 m/s being recorded. The wind is strong enough and the dust particles small enough to create massive dust storms that can obliterate the surface of Mars as seen from Earth for weeks on end.

The deserts of Mars do have Earth-style wind erosion, with oxidation and weathering of rocks on the surface. Dust and sand is also blown about and deposited in layers.

Water erosion on Mars appears to have happened at some time in its history. There are twisting surface valleys caused by rivers, many with clearly visible tributaries.

These are possibly dried up water-eroded channels like those seen on Earth. However, some scientists think that some of the sinuous channels are not signs of water erosion but mud flows set off by volcanic eruptions melting subsurface water.

This does mean that huge amounts of water may still be present in the form of permafrost under the surface. Other water may be locked up in the polar caps – the northern one, especially.



NASA/Science Photo Library

***America's Viking 2** lander visited the barren surface of Mars. Part of the spacecraft is shown in the foreground. The dish is a high-gain antenna, pointed towards Earth. This picture is believed to show the true colours of Mars.*

Just amazing!

WRIT IN SAND

IN 1874, A FRENCHMAN SUGGESTED BURNING MESSAGES ON THE MARTIAN DESERTS WITH A HUGE BURNING GLASS.

Paul Raymonde

No signs of life

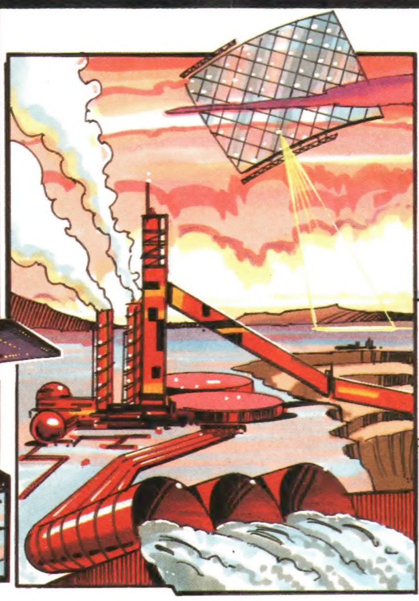
The more obvious signs of water erosion appear on the oldest parts of Mars – the uplands – so any water erosion must have happened a very long time ago. The conditions are such that liquid water cannot now exist on the surface.

The surface soil is made of iron-rich basaltic lavas. The pinky-red colour of the soil and the rocks is most likely caused by the oxidation (rusting) of iron-bearing minerals. So far, Mars has not shown any signs of life, whether in the soil or in the air.

INTO THE FUTURE

BRINGING LIFE TO MARS

▲ *Spreading dark material over polar caps would cause them to melt. Mining Mars's moons Deimos and Phobos would produce oxygen, water and fuel.*



▲ *Much of the Martian water is held as ice in the permafrost and could be mined. The ice could then be melted using huge orbiting mirrors.*

▲ *Farming might then be possible on the Martian surface. Crops would have to be grown under glass, using subsurface water and genetically engineered plants.*

Joe Lawrence

SHAPING UP IN SPACE

SPACE FLIGHT IS BAD FOR your health – and that is official. It is a wonder that anyone should want to join the growing list of 220 Space travellers, judging by what happens to their bodies up there in orbit.

The weightlessness of Space causes many changes in the body, including nausea, disorientation, motion sickness, muscle loss, a loss of calcium and bone, weakened heart function, decreased exercise capacity, reduced blood volume and changes to the blood cell levels.

Not every astronaut suffers from every symptom. For example, only about half feel Space sick and then for only about two days at the start of their journeys. Many of the other symptoms are well understood and in fact stabilize after the body has been weightless for several months.

Wasted away

But one of the most worrying effects of really long Space flights is muscle and bone loss. The 600 muscles (one is the heart) and 200 bones of the body are designed to operate in gravity. Without it, muscles wither and bones become smaller and weaker.

The early astronauts flew inside very small capsules and had little room to lift an arm or leg, let alone exercise. But they flew comparatively short Space flights. Later on, after longer flights, such as the 17-day mission in Soyuz 9 in 1970 the Russian cosmonauts had to be lifted out of their craft like fish at the end of a line. They could not stand up for days.

In orbit

What would have happened to these travellers had they flown around the Earth for, say, 365 days – the duration of the longest manned Space flight? If they had not wasted away in Space,

Extravehicular activity *is one of the best ways of exercising in Space. Here, astronaut Sherwood Spring assembles an experimental structure while in orbit.*

NASA/Science Photo Library

Joe Lawrence

In a weightless environment *blood tends to accumulate in the upper half of the body. By simulating the pull of gravity, a negative pressure suit draws the blood back to the lower body.*

they would certainly have been finished off during their return to Earth. Their weakened muscles and bones would not have withstood the G-forces of re-entry or the continuous one G gravity on the Earth.

Jogging in Space

However, when Yuri Romanenko came home after 326 days in the spacious Mir station, in 1987, he wanted to climb out of his Soyuz TM ferry capsule. Cautious doctors had him carried on a stretcher to a waiting helicopter. The frustrated Romanenko was so determined to prove his fitness that as soon as he reached base, he went for a jog. Why was he so fit? Because he jogged in Space.

Exercise is the best antidote for the ills of weightlessness, particularly weakened muscles and slow loss of minerals in the locomotion bones of the body. On long-duration Soviet flights, cosmonauts must exercise for two and a half hours every day.

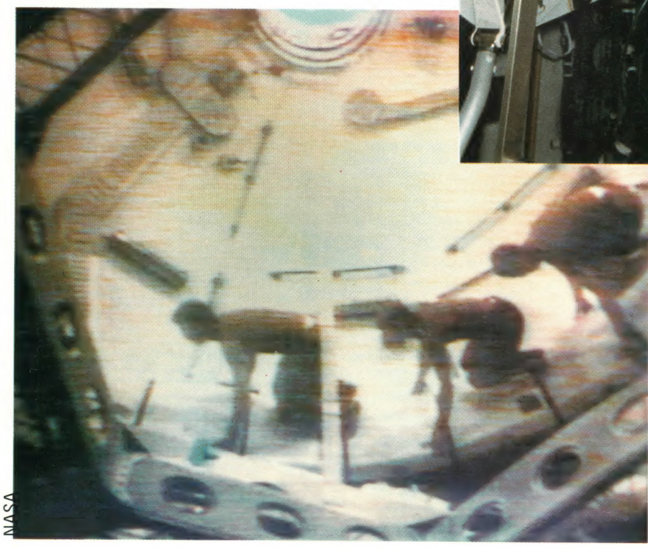
The Soviet Mir Space station is equipped with a treadmill and ergometer. To avoid boredom, the treadmill on Mir is at the aft end of the core module, so an exercising cosmonaut can look down the length of the module rather than just stare at a wall. Music is often played ghetto-blaster style to accompany the routines.

Floating on air

Formal exercise is complemented by the exercise an astronaut gets from floating around. On a US Skylab flight, three astronauts were filmed 'running' around the interior of the Space station and criss-crossing rapidly, by rebounding off the walls. Astronauts also invent games and perform pirouettes, curled up or with arms outstretched as if they are flying.

The most strenuous exercise can be taken making a Space walk. Working in Space is doubly difficult because the astronaut must fight all the time against a tendency to float away from the spacecraft or the object he is working on. At the end of one Space walk, in 1988, the two cosmonauts were so exhausted that, according to a colleague, they were too weak 'even to lift a teabag'.

NASA



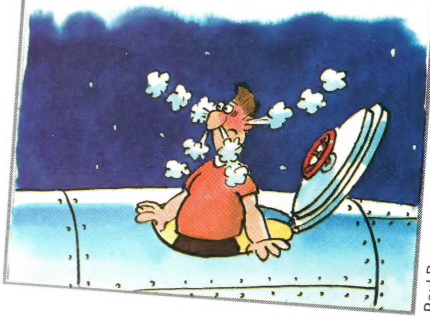
NASA

Keeping fit *in the zero gravity of Space. Bill Nelson, wired up for tests, uses a treadmill in the Space Shuttle. Filmed by a television camera, astronauts (left) get into starting positions for a race around the domed Orbital Workshop inside Skylab 2.*

Just amazing!

BOILING POINT

IN THE VACUUM OF SPACE, IT IS RECKONED THAT AN ASTRONAUT'S BLOOD WOULD BEGIN TO BOIL IN JUST 30 SECONDS, IF HE WAS NOT PROTECTED BY HIS SPACESUIT.



Paul Raymonde